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PROJECT 1 - NASA GRANT NAG10-0058

INTELLIGENT INTERACTIVE VISUAL DBMS

Research Team Leader:

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RESEARCH GOALS AND METHODS

PROBLEM: To Determine the Feasibility of Intelligent and Direct Interfacing Between AI Expert Systems and Mass Storage Laser-Optical Technology

OBJECTIVE: To Investigate and Demonstrate the Intelligent Interfacing of AI Expert Systems and Mass Storage Devices with Emphasis on Visual Data Collection, Storage, Retrieval, and Transmission

APPROACH: Use Research Methodology and Develop Demonstration Systems to Assess the Feasibility of Interfacing Two Relatively New Technologies

APPROACH

GENERAL

* Identify and Establish Needed UCF Resources/Research Team
* Investigate SPC, TGS, and Other Organizations Methods of Utilizing, Authorizing, Acquiring, Storing, and Retrieving Close-Out Photography
* Conduct Literature Searches and Evaluation of Commercially-Available Expert System Shells
* Conduct a Comparable Activity for Laser-Optical Devices
* Identify Relevant Interfacing and Database Technologies
* Acquire Necessary Hardware and Software Tools
* Build Demonstration Prototype Systems

APPROACH (CONT)

LONG-TERM

* Adjust Faculty and Student Composition (As Required) Over Life of Research Project (Matrix Project Team)

* Identify and Investigate Advanced Concepts Needed for Technology and Systems Integration

* Consider Eventual Target Computer Host (SPDMS II) in Research Designs

* Build Working Research System Prototype(s)

* Develop and Disseminate Research Reports and Papers

RESEARCH GRANT STATUS

* Preliminary Project Activities Began in May 1989

* First Status Review Held September 5, 1989

* Three-Year Cooperative Agreement Developed and Signed

* Project Divided Into Three Phases:
  - o First Year -- Analog Laser-Optics
  - o Second Year -- Digital Laser-Optics
  - o Third Year -- Advanced Technology and Integration

* First Year of Project Began In December 1989

* Most of Administrative Start-Up Problems Over

* Faculty Support by Dr. J. Ragusa (Business), Dr. G. Orwig and A. Barron (Education), and A. Shaykhian (Engineering)

* Five to Thirteen Graduate Students Involved Via Direct Project Funding, Course Assignments, or Independent Study

RESEARCH GRANT STATUS (CONT)

* College of Business Has Assigned Two Lab/Research Rooms for Project Duration
* Working and Informational Relationships Established With Appropriate KSC Organizations and Individuals
* KSC Close-Out Authorization, Collection, Processing, Storage, Retrieval, and Distribution Systems Understood
* SPC Close-Out Photo Users Surveyed and Results Summarized
* All Relevant Research Literature and Information Being Organized Using Newly-Developed dBase IV Database System
* AI Center of Excellence for Business Applications (AI-CEBA) Established As Spinoff
* Team Members Have Toured SPDMS II Host Facility and Attended Various Systems Briefings

RESEARCH GRANT STATUS (CONT)

* SPDMS II Compatibility With Various Interfaces Under Study

* Sample Set of Close-Out Photographs Obtained

* Prototype Photo Classifier and Retrieval Expert Systems Built and Demonstrated to KSC Operational Users

* Phase II Photo Classifier and Retrieval Study Underway

* Three Team Members Attended SALT-Orlando Vendor Exhibits and Tutorials on Hypertext, DVI, CD-ROM, and Related Technologies

* Teledyne-Brown/Sony Operational Payload System Identified

* Comparison Study of Laser Disc Front-End Systems Begun (Expert System, dBase, and Hypertext)
  - o Expert System - Complete
  - o dBase - 50% Complete
  - o Hypertext - Not Started

RESEARCH GRANT STATUS (CONT)

* Expert System/Database Interfacing Continues
* Database-to-Laser Disc Prototype Built
* Text and Visual Retrieval Technologies Under Study (Using Dialog and Other Sources)
* Object Oriented Programming (C++) and Use of Hypetext Under Study for Project Applications
* Research Team Members Visited Various Orlando-Area Technology Organizations (Including Harris)
* Research Equipment Ordered Includes:
  - o Intel 386 Tower PC (For DVI Compatibility)
  - o Panasonic OMDR/Supporting Camera
  - o Zenith 386e Laptop
* Equipment Purchases Slightly Behind Schedule

RESEARCH GRANT STATUS (CONT)

* Expert System Software Available Includes:
  - o PC-Easy and PC-Plus
  - o VP Expert/SQL (Purchased)
  - o 1st-Class Hypertext (Purchased)
  - o EXSYS
  - o Level 5 (Purchased)
  - o GURU
  - o Nexpert Object (Under Consideration)

* All Purchases Within Budget

* Expert System For Expert System Shell Selection Under Development Using 1st-Class

* Transmission Technology Under Review

* Recent Interest In UCF Research For LSOC Engineering Data Access & Management System (EDAMS) Application

SUMMARY

* Little Evidence of Research or Operational Intelligent Interactive Visual Database Management Systems

* Initial UCF Research Indicates that Expert Systems and Laser-Optics Technologies Can be Interfaced for a Wide Variety of Applications Including KSC Close-Out Data Acquisition, Storage, and Retrieval

* Initial KSC Prototype Provides Intelligent and User-Friendly Interface to Moderately-High Resolution Still Photographs, Text, Motion Sequences, Graphics, and High Quality Sound

* Numerous Organizations Interested in Integrated Technologies and a Large Number of Applications Exists

* Shuttle Close-Out Photography is an Ideal Research Application

* Team Research Activities Are On Schedule and Within Budget

* Design and Use of Integrated Technologies Limited Only by the Imagination of Those in Need

DEMONSTRATION SCHEDULE
1:00 -3:30 p.m.
(Room 334-CEBA II)

* dBase IV Project Reference System (Articles, Books, Prototypes, and Shells)

* Laser-Optical Prototype System (PC-Easy and dBase IV)

* Expert Systems Photo Classifier and Retrieval Prototypes

NASA/University of Central Florida

INTELLIGENT INTERACTIVE VISUAL DBMS

Project Status to NASA: April 24, 1990

Research Team Leader:

Dr. James M. Ragusa
Associate Professor
College of Business
Department of Management
University of Central Florida

PROJECT TITLE

INTELLIGENT INTERACTIVE VISUAL DBMS

NASA/University of Central Florida
Cooperative Agreement

DESCRIPTION OF PROJECT

PROBLEM: To determine the feasibility of intelligent and direct interfacing between AI expert systems and mass storage laser-optical technology

OBJECTIVE: To investigate and demonstrate the intelligent interfacing of AI expert systems and mass storage devices with emphasis on visual data collection, storage, retrieval, and transmission

APPROACH: Use research methodology and develop demonstration systems to assess the feasibility of interfacing two relatively new technologies for a specific Lockheed Space Operations Company (LSOC) Shuttle Processing Contract (SPC) application

CURRENT STS OPERATIONS SITUATION

* Shuttle Safety and Reliability Program requires close-out photography for each STS mission
* Present method is for user to take pictures during close-out process using Nikon cameras and 35mm color slide film
* Approx. 100,000 taken for each STS pre-launch flow
* Color 8 x 10" photographs mailed to various U. S. locations for Orbiter, ET, and SRB engineers to review
* Normal distribution is two-weeks with priority possible
* Photographs are an important part of the launch readiness verification process
* Large active and inactive photographic inventory exists at multiple locations
* Hard copy photographs manually stored and retrieved
* Caption information and other data is limited

WHAT WE INTEND TO ACCOMPLISH

* Jointly conduct applications research on the development of intelligent interactive visual data base management systems

* Primary applications goal is to enhance the existing SPC close-out and problem statusing photographic acquisition, storage, and retrieval systems

* Additional objective is to better understand requirements and methods for electronic enhancement and image transmission between NASA/KSC and other locations

* Technology is to be compatible with planned SPC data management system (SPDMS-II)

HOW THIS DEVELOPMENT WILL ENHANCE OPERATIONS

* Effort is part of an overall LSOC goal of achieving a paperless technical data recording, retrieval, and analysis system

* Ultimate operational goal is to improve STS processing productivity, efficiency, and reduce costs

RESEARCH APPLICATION APPROACH

CURRENT YEAR

* Identify and establish needed UCF resources/research team and NASA/contractor technical contacts
* Investigate SPC, TGS, and other organizations methods of utilizing, authorizing, acquiring, storing, and retrieving close-out photography
* Conduct literature searches and evaluation of commercially-available expert system shells
* Conduct a comparable activity for laser-optical devices
* Identify relevant interfacing and database technologies
* Investigate spectrum of visual data base retrieval methods
* Acquire necessary hardware and software tools
* Build demonstration prototype systems

RESEARCH APPLICATION APPROACH (CONT)

SUBSEQUENT YEARS

* Adjust faculty and student composition (as required) over life of research project (matrix project team)

* Identify and investigate advanced concepts needed for technology and systems integration

* Consider eventual target computer host (SPDMS-II) in research designs

* Build working research system prototype(s)

* Develop and disseminate research reports and papers

HARDWARE AND SOFTWARE REQUIREMENTS

* Hardware required (PC-based systems):

First year (analog technology/expert systems integration)
- o Existing UCF PC's
- o Pioneer laser disc and Sony monitor
- o Intel 386 tower PC (for DVI compatibility)
- o Panasonic OMDR/supporting camera
- o Zenith 386e laptop

Second year (digital technology/expert systems integration)
- o Intel DVI chip set or equivalent
- o Still video system
- o Frame grabber

Third year (advanced technology)
- o HDTV camera and monitor
- o Other equipment as required

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HARDWARE AND SOFTWARE REQUIREMENTS (CONT)

* Software required (commercial shells):

  First year (analog technology/expert systems integration)
  - o PC-Easy and PC-Plus (UCF provided)
  - o VP Expert/SQL (purchased)
  - o 1st-Class Hypertext (purchased)
  - o Exsys (UCF provided)
  - o Level 5 (purchased)
  - o Guru (UCF provided)
  - o ART-IM (UCF provided)
  - o Kappa (under consideration)
  - o CLIPS (under consideration)
  - o "C" programming language (UCF provided)

* Second year (digital technology/software integration)
  - o Nexpert Object (under consideration)
  - o Other expert system shell software (as required)
  - o Image processing (as required)
  - o Artificial neural network and pattern matching
  - o Additional supporting software as required

* Third year (advanced technology and systems integration)
  - o Supporting software TBD

RESEARCH GRANT STATUS

* Preliminary project activities began in May 1989

* First NASA/KSC status review held September 5, 1989

* Three-year cooperative agreement developed and signed

* Project divided into three phases:
  - o First year -- analog laser-optics/expert systems
  - o Second year -- digital laser-optics/expert systems
  - o Third year -- advanced technology and integration

* First year of project began in December 1989

* Most of administrative start-up problems over

* Faculty support by Dr. J. Ragusa (Business), Dr. G. Orwig and A. Barron (Education), and A. Shaykhian (Engineering)

* Five to thirteen graduate students involved via direct project funding, course assignments, or independent study

RESEARCH GRANT STATUS (CONT)

* College of Business Administration has assigned two lab/research rooms for project duration (CEBA II)

* Working and informational relationships established with appropriate KSC organizations and individuals

* KSC close-out authorization, collection, processing, storage, retrieval, and distribution systems understood

* SPC close-out photo users surveyed and results summarized

* All relevant research literature and information being organized using newly-developed dBase III+ database system

* AI Center of Excellence for Business Applications (AICEBA) established as spinoff

* Team members have toured SPDMS-II host facility and attended various systems briefings

* SPDMS-II compatibility with various interfaces under study

RESEARCH GRANT STATUS (CONT)

* Sample set of close-out photographs obtained
* Prototype photo classifier and retrieval expert systems built and demonstrated to KSC operational users
* Phase II photo classifier and retrieval study completed
* Three team members attended SALT-Orlando vendor exhibits and tutorials on hypertext, DVI, and CD-ROM
* Teledyne-Brown/Sony operational payload system identified
* Comparison study of laser disc front-end systems begun (expert system, dBase, and hypertext)
    - o Expert system - complete
    - o dBase - 75% complete
    - o Hypertext - not started
* Expert system/database interfacing continues

RESEARCH GRANT STATUS (CONT)

* Database-to-laser disc prototype built
* Text and visual retrieval technologies under study (using Dialog and other sources)
* Object oriented programming (C++) and use of hypetext under study for project applications
* Research team members visited various Orlando-area technology organizations (including Harris)
* Equipment purchases within budget but behind schedule
* Expert system for expert system shell selection under development using 1st-Class Hypertext
* Transmission technology under review
* Recent interest in UCF research for LSOC Engineering Data Access & Management System (EDAMS) application

CONCLUSIONS

* Little evidence of research or operational intelligent interactive visual database management systems

* Initial UCF research indicates that expert systems and laser-optics technologies can be interfaced for a wide variety of applications including KSC close-out photography acquisition, storage, and retrieval

* Initial KSC prototype provides intelligent and user-friendly interface to moderately-high resolution still photographs, text, motion sequences, graphics, and high quality sound

* Numerous organizations interested in integrated technologies and a large number of applications exists

* Shuttle close-out photography is ideal research application

* Team research activities are on schedule and within budget

* Design and use of integrated technologies limited only by the imagination of those in need

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Phase II Research and Development of NASA Photo System to Aid in Classification (NAPSAC) and Photo Retrieval and Identification System Expert (PRAISE)

Project Report

by

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Prepared for
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MAN 6908
NASA Directed Independent Study
April 20, 1990

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Phase II Research and Development of NASA Photo System to Aid in Classification (NAPSAC) and Photo Retrieval and Identification System Expert (PRAISE)

INTRODUCTION

Beginning in September 1989, two expert system prototypes were developed in support of a University of Central Florida/NASA grant. This research was undertaken to determine the applicability of expert systems technology to aid in the classification and retrieval of photographs. The prototypes were limited to Shuttle related photographs taken at the Kennedy Space Center (KSC). The NASA Photo System to Aid in Classification (NAPSAC), and the Photo Retrieval And Identification System Expert (PRAISE), were the results of the semester's efforts.

Once both projects had been studied and reviewed, the thrust of this independent study became clear. Both papers suggested that the concept of using expert systems technology for classification and retrieval of photographs was good, but Texas Instruments' PC Easy was not the appropriate tool to use in developing a real-time system. A "Phase II" was suggested to study other expert systems shells, and to select one that can handle a large data base, is user-friendly, and can efficiently interface with graphics and database programs.

The Phase II research and development was carried out by first screening commercially available expert system shells accessible to the project team. The project team identified five expert system shells that were capable of handling the technical requirements specified by the Phase I project teams. These shells were evaluated based on their ability to exceed the performance standards of Personal Consultant Easy, as judged by the Phase II project team. Actual experience with the shells allowed the project team to determine how they would perform in a realistic classification and retrieval setting.

METHODOLOGY

The expert system shells were evaluated by a project team that consisted of two MBA students from UCF. Both team members shared all responsibilities and worked jointly in all aspects of the project. In evaluating the expert system shells, the team had access to an IBM PS/2 Model 50, the UCF LAN, and an extensive library of expert systems literature located in the AI CEBA NASA Project Lab.

The team composition and background of each member is as follows:

Fred Damiano received his Bachelor of Science Degree in Computer Information Systems from Bentley College in 1983 and plans to complete his MBA in May, 1990. For the past seven years he has worked in the computer industry, specifically in the area of applications software development. He is currently a Programmer Analyst with Travelers/EBS, and was the Software Specialist on the PRAISE project team.

Paige Leone graduated from Stetson University in 1986, with a Bachelors degree in Business Administration. She was employed by Harris Corporation as a financial analyst from 1986 to 1989 and plans to complete her MBA requirements at the University of Central Florida in May, 1990. She was a Knowledge Engineer on the NAPSAC project team.

SELECTING THE EXPERT SYSTEM SHELLS TO BE EVALUATED

There were five expert systems shells available to the project team. They are: Texas Instruments' Personal Consultant Plus (PC Plus), Paperback Software's VP EXPERT SQL, Programs In Motion's 1st Class Hypertext (1st Class), Information Builder's Level 5, and Micro Data Base Systems' Guru. After reading literature on benchmark studies conducted on these shells, the team decided to evaluate all five. Benchmark tests conducted on these shells indicated that they met the technical requirements necessary to implement a real-time photograph classification and retrieval system. Real-time research on these shells focused on their ability to meet the functionality of the NAPSAC and PRAISE prototypes, and the requirements specified in the Phase I reports.

Each of the shells that were tested are discussed in detail in the following sections. The project team became acquainted with each shell through the tutorials, sample knowledge bases, and technical reference manuals.

EVALUATION CRITERIA

The expert system shells were evaluated on their ability to meet the functionality and flexibility of PC Easy. Any shortcomings of one of the expert system shells to meet this requirement was studied so that a "workaround" method could be identified. Our evaluation of these shells is based entirely on their ability to support a photo classification and retrieval process as defined and observed during the Phase I prototype development.

EXPERT SYSTEM SHELL EVALUATIONS

1st Class Fusion Hypertext

General Summary

We found 1st Class easy to learn. The development and consult modes are very user friendly. An end user would need no prior exposure to 1st Class in order to be able to interface with the shell, given a run-time version. During knowledge base development, the shell guides the developer through the creation of factors (parameters) and their associated values. All possible results are entered simultaneously as examples into a spreadsheet type template. The system writes its own rules and presents them in a knowledge decision tree. This is a strong feature of the shell as it enables a clear visualization of the development of the knowledge base at all stages.

The hypertext feature of 1st Class would be a valuable asset in the photo classification and retrieval process. The ability to develop help screens with associated hypertext cards would help in several key areas. First, it could go a long way in eliminating the terminology consistency problem in classifying photographs. Secondly, the retrieval process would benefit from this increased accuracy. Additionally, hypertext can be used to provide the user with assistance in accurately answering questions, thus increasing the confidence level in classifying and retrieving photographs.

The database access provided by 1st Class is also quite good. 1st Class allows both read and write access to Dbase III and Dbase IV files. The expert system shell provides database features such as seek, append, get, and put. 1st Class can access four types of fields. They are character, numeric, date, and logical.

Two final areas where 1st Class performs well are in its ability to display graphic images and to provide meaningful help screens. 1st Class comes with a utility program to capture graphic images that can be displayed on the screen during consultations. In addition, 1st Class provides the ability to develop customized help screens to assist an end user. Both of these features are important in the development of a photo classification and retrieval system.

Problems and Potential Workarounds

Despite the unique advantages of 1st Class, it has deficiencies that need to be addressed for the classification and retrieval application. At the present stage of the research into the viability of a classification and retrieval expert system, it is necessary to have extensive storage and free-form textual input capabilities. This is where the drawbacks in 1st Class exist.

First, there is an inability to do free form input of text within 1st Class. We contacted technical support personnel at 1st Class to discuss this situation. They verified that single line input of textual data cannot be done within the development interface. We were told that some of their customers are writing external calls to editors and C functions to accommodate for this deficiency. The product documentation provides straightforward instructions on how to use program calls from within 1st Class. This would essentially by-pass the single line textual input problem.

If the amount of required textual input is minimal, this would be an acceptable solution to the problem. The Phase I prototypes have shown that there are only two parameters that require textual input. They are the photographer's name and a photo description.

One of the most attractive features of 1st Class is it's simplicity. Writing external calls to editors and C functions adds complexity to the shell. It also does not lend itself to easy modification by non-technical personnel at KSC. However, when considering the numerous advantages of 1st Class, this problem is relatively minor.

Second, there are size and storage space problems. 1st Class only allows 32 factors and 128 values for each factor. The classification and retrieval application as it stands will exceed the factor limitation, requiring approximately 50 factors. This could be overcome by chaining together more than one knowledge base. However, this will come at the expense of execution speed. This is a less than optimal situation, but the use of 386 and 486 machines should compensate for this problem.

There is also a limit of 65,000 records accessible in a data base. Present estimates indicate that 70,000 photographs are taken in preparing a shuttle for each launch. Thus, the 65,000 record maximum is a constraint. However, this could be overcome by having separate databases for each launch processing cycle. Each database could be linked to the specific mission numbers (ie. STS-26R). If photos are requested that span multiple missions, 1st Class can access four databases simultaneously, and can scan any number of them by closing one database and opening another.

VP Expert/SQL

General Summary

VP Expert/SQL was relatively easy to learn through the use of its tutorial, sample knowledge bases, and well laid out documentation. The development mode consisted of a fairly technical approach to building a knowledge base. The shell's environment is programming-oriented and requires more up-front time

than PC Easy and 1st Class in getting acquainted with its capabilities. All rules, parameters, and goals are input into a single text file. This text file contains all the components of the knowledge base.

The shell has a split-screen (windowing) capability that is very helpful during the development process. When in the consult mode, the developer is able to watch the firing of the rules. This aids in the debugging process. Additionally, this windowing allows the developer to monitor the firing and execution of SQL statements, which is an excellent feature.

In general, the consult mode is user friendly. An end user would need no prior exposure to VP Expert/SQL in order to be able to interface with the shell, given a run-time version. The questions and answers are displayed on a scrolling screen. Selecting a question's response requires that the user press the enter key and then verify the response with the 'End' key. Each response is marked with an identifying triangle, which is a good visual aid. However, the double validation can be frustrating.

VP Expert/SQL, like 1st Class, has the feature of rule induction. However, this induction capability is not resident in the expert system shell, making it less efficient than 1st Class. In order to take advantage of this capability, examples have to be set up in a spreadsheet or database file and then imported into VP Expert/SQL.

One of the major advantages of VP Expert/SQL in supporting a photo classification and retrieval process is its ability to interface with relational data bases. SQL (System Query Language) provides access to relational databases on micro, mini, or mainframe computers without having to actually import the data. The expert system serves as a front end to either local or remote databases.

VP Expert/SQL also provides the ability to create hypertext files. The hypertext files are ASCII text files that are created outside of VP Expert/SQL, and are referenced through rules in the knowledge base. As in the case of rule induction, this method is not as efficient as the one used in 1st Class since the whole process is not resident within the expert system shell.

Problems and Potential Workarounds

VP Expert/SQL suffers from some key deficiencies that need to be addressed. Despite its ability to interface with relational databases, there are drawbacks in the areas of rule development, help screens, error messages, graphics, and textual input.

During rule development, rules are formatted into IF...THEN statements within the knowledge base and are fired based on their

sequential location within the text file. Rules are not fired through the shortest route to a conclusion, which is inefficient. The placement of the rules in the knowledge base is absolutely critical. This is a disadvantage from a photo classification and retrieval standpoint.

The Phase I prototypes contained knowledge bases with a total of 115 rules. If the prototypes were expanded and completed, maintenance on a continual basis would be difficult. The software specialist would have to identify exactly where new rules needed to be placed in order to be as efficient as possible. This is a difficult and time consuming task, and to some degree defeats the purpose of working with an expert system shell.

VP Expert also has shortcomings in the area of help screens and error messages. Basically, the developer cannot incorporate customized help screens for each parameter. This is a major drawback since help screens (both text and graphics) will be a significant component of our NASA application. In addition, we found error messages to be quite cryptic during development, falling significantly below the level of PC Easy. We were not able to identify any potential solutions to these problems.

Graphics are not as easy to create as in 1st Class or PC Easy. In VP Expert/SQL, an external call can be made from within the knowledge base to display a graphic image. However, the graphic image cannot be displayed simultaneously with the VP Expert/SQL consulting screen.

Similar to 1st Class, VP Expert/SQL also has limited abilities in the entry of single line textual data. A maximum of forty characters are allowed for textual input. There is also a forty character limit on the values that can be associated with a parameter. Additionally, the characters-must-be-connected (like this), even if quotes are used. This is another area in which we were not able to identify a potential workaround, with the exception of external calls.

Another related problem is that fields cannot be defined as text, numeric, date, etc. For all intents and purposes, all data in VP Expert/SQL is considered to be text. This will present a problem when a retriever wants to find a photo within a specified time period. In addition to this, there is no validation to ensure that the user is entering data correctly (eg. 1/12/90 vs Jan. 12).

In summary, the required mode of rule writing within VP Expert/SQL will make it difficult for untrained individuals to change the knowledge base. This contradicts the requirement stated by the Phase I development teams to have a shell that lends itself to easy modification. In a real-time implementation, VP Expert/SQL would require maintenance by an individual that has an intermediate understanding of programming techniques.

LEVEL 5

General Summary

LEVEL 5 is an expert system shell that takes a significant amount of time to learn and understand. The shell requires the use of a Programming Rule Language (PRL) to develop the knowledge base in a text file. LEVEL 5 does allow knowledge base development in the "non-document" mode of a word processor. There is no real tutorial in LEVEL 5. The only way to learn how to use it is to print out one of the sample knowledge bases and track the flow of a consultation.

LEVEL 5 requires that a knowledge base be broken down into as many as 10 different sections. At first this appears to be an efficient organization of the text file, but in reality it is a very intricate setup. The complications arise as a result of the way parameters and their associated values are handled. LEVEL 5 recognizes key words and phrases as parameters and their associated values based on their explicit placement within the text file. This means that they must be entered uniformly throughout the text file, making the creation and maintenance of the knowledge base very difficult and susceptible to human error.

The consult mode is very satisfactory. An end user answers questions by picking from a list of possible answers or entering text. Textual input can be up to 80 characters long. The user can indicate their confidence in an answer by positioning a confidence bar at the appropriate value. LEVEL 5 has the ability to access external programs directly from a knowledge base and interfaces with Dbase III. Additionally, knowledge bases are run in compiled form, which is more efficient than running a full version.

As previously mentioned, LEVEL 5 is written in PRL. Rules are written in the format of IF..AND..OR..THEN..ELSE. Similar to VP Expert/SQL, sequential placement of rules is critical. The order of the firing of the rules is determined by their placement within the text file. Thus the firing of the rules is determined by the developer.

Problems and Potential Workarounds

Although LEVEL 5 has no severe deficiencies, it does have weaknesses in its ability to support a photo classification and retrieval system. The major drawbacks are very similar to those discussed in relation to VP Expert/SQL. They are rule development, help screens, error messages, and graphics. The drawbacks are as follows:

- Rules are formatted into IF-THEN statements within the knowledge base and are fired based on their sequential location within the text file.

- A software specialist would have to identify exactly where a rule needed to be placed to be as efficient as possible when updating the knowledge base.

- A developer cannot incorporate customized help screens for each parameter. In addition, error messages were found to be cryptic.

- Graphics are not as easy to create as in 1st Class or PC Easy.

Rather than restating the problems connected to these drawbacks, please refer to the "Problems and Potential Workarounds" section under VP Expert/SQL.

In summary, the required mode of rule writing within LEVEL 5 would require a specially trained developer to create and maintain the expert system. This would be a major factor from a cost standpoint in choosing LEVEL 5 to support the classification and retrieval process. Although the shell has some powerful capabilities, it does not have some of the more advanced and desired features such as hypertext, visual knowledge trees, and a more sophisticated developer interface.

Guru

General Summary

Guru is an expert system shell that was designed specifically for business applications. This is evidenced by the business tools that are available within the shell itself. These tools include a spreadsheet, database, text processing, business graphics, and a customized report generator. An optional component in Guru, unique to all the shells we have reviewed, is its remote communications ability. This functionality would allow a user from any NASA space center to interact with the photo classification and retrieval expert system. This is a big plus in supporting the long range goals and objectives of SPDMS II.

It takes a substantial amount of time to learn and understand Guru. Although Guru has several powerful capabilities, the tradeoff is that they are complex and difficult to master. The documentation manuals are large, cumbersome, and very difficult to use. Although they are exhaustive, it is difficult to find specific information. In addition, the manuals have been written for persons who are already familiar with companion products from the firm that markets Guru.

Guru allows several methods of expert system development. A user can develop an expert system application via menu guidance, natural language conversation (CHAT), or command language. External editors can also be used for knowledge base development, and the files can then be imported into Guru. These development capabilities are in contrast to the straight programming environment found in Level 5.

Guru also has a good user interface. In the consult mode, an end user answers questions by inputting numerical data, picking answers from a list, or entering text. The user can indicate their confidence in an answer by entering a confidence factor. Guru also receives good marks for its ability to generate help screens. This is another factor that improves the overall user interface.

Guru has the ability to interface with external databases. This includes both Dbase III and SQL type databases. Access to these databases is in addition to its own internal database capabilities. Guru can also make external program calls to other software. The only limitation is that the programs must be able to fit in the available memory.

Rules are in IF...THEN format, and have the ability to include mathematical calculations. Each knowledge base requires an "Initialization" section that contains pertinent preliminary information for the knowledge base. This is cumbersome and is created in a way that is different from the development of rules. The coding in this section is very cryptic and programming oriented. The developer error messages are also cryptic. Another drawback with Guru is its inability to generate rules through automatic rule induction. This proves to be a desireable feature, since the generated rules tend to be written very efficiently. In order to fully utilize the capabilities within Guru, a specially trained programmer would have to be hired.

Problems and Potential Workarounds

Guru does not possess severe technical deficiencies in terms of its ability to support a photo classification and retrieval system. However, there are some concerns as to the viability of using Guru. Our major areas of concern include the following:

- It would be necessary to hire a specially trained programmer to create and later make modifications to the knowledge base. This is not seen as an ideal situation.

- Although the shell has the ability to generate business graphics (ie. pie charts, bar graphs, etc.), an external graphics program (ie. Dr. Halo) would still have to be utilized to create graphics.

- Guru does not support a means for utilizing hypertext. As has been previously stated, this is considered to be an important feature for a real-time implementation of a photo classification and retrieval system.

- One of the goals of SPDMS II is to provide access to systems that are usable by large numbers of personnel at KSC. If Guru is part of SPDMS II, it would likely be utilized only by small groups of highly technical personnel. This is not seen as a cost-effective means of making expert systems technology available to all SPDMS users.

PC Plus

General Summary

PC Plus is essentially an enhanced version of PC Easy. It has a friendly developer interface and takes little time to learn. The primary difference between PC Easy and PC Plus is an enhanced developer interface. For example, PC Plus provides a TREE ON/OFF command which provides a visual representation of the knowledge base. PC Plus also supports expanded or extended memory.

PC Plus allows for the development of Scheme and LISP functions, in addition to using the shell's interface. However, this added capability is not perceived to have an impact on the photo classification and retrieval application. As discussed in reference to VP Expert/SQL and LEVEL 5, complicated programming requirements make the shells less attractive than those with no programming requirements. As long as the development interface provides the necessary tools and power, it is not deemed advantageous to utilize the Scheme and LISP functions.

The primary differentiating feature of PC Plus is its frame capability. Frames break up a knowledge base into hierarchial subsections, each with its own set of rules and parameters. Each frame consists of the familiar GOALS, PROMPTEVER, TRANSLATION, INITIALDATA, and DISPLAYRESULTS commands. The primary benefit derived is that of increased efficiency. Unlike PC Easy which scans all parameters and rules, PC Plus only accesses a frame if it is relevant to the current consultation. Frames would be beneficial to the photo classification and retrieval application. The knowledge bases could be broken down into frames for each contractor, KSC program, and space shuttle component (orbiter, external tank, solid rocket boosters).

Problems and Potential Workarounds

Although PC Plus is an expert system that is flexible and easy to work with, it suffers from the same drawbacks as PC Easy that were discussed in the written summary of the Phase I findings (see

Appendix I).

After reviewing several expert system shells, hypertext capability has proven to be a strong asset for the classification and retrieval systems. From a classification standpoint, the ability to key off certain words or phrases for textual or graphical aid is invaluable. This is where PC Plus is at a disadvantage, as it does not have hypertext capabilities. In addition, we were not able to identify potential workarounds to this problem.

Both NAPSAC and PRAISE were loaded into PC Plus to see if there would be a noticeable increase in processing speed. No difference was found. In fact, PC Plus seemed to be even slower than PC Easy. Although a 286 machine was utilized, running PC Plus on a 386 machine might not provide the necessary power to significantly improve processing speed.

In general, PC Plus does not provide a distinct advantage over PC Easy in reference to the photo classification and retrieval application. PC Plus also does not have some of the advanced features available in the other expert system shells that were evaluated. Examples are hypertext, automatic rule induction, and SQL capability.

EVALUATION CRITERIA TABLE

Based on our research on the five expert system shells and prior experience with the NAPSAC and PRAISE projects, we have a good indication of the shell that should be utilized in Phase III. In order to substantiate our recommendation, we used an evaluation criteria table. This table consists of the six major areas of concern in developing a photo classification and retrieval expert system. Each criteria was rated for each of the expert system shells, based on their ability to meet the needs of NAPSAC and PRAISE.

This quantification provides us with an additional means of objectively recommending an expert system shell for further development of NAPSAC and PRAISE. Consideration was given as to the applicability of the expert system shell to other NASA business-related applications and the implementation of SPDMS II. The results of the shell analyses are summarized in the following table.

Evaluation Criteria	1st Class	VP/SQL	Level 5	Guru	PC+
Developer Interface	5	3	1	2	4
User Interface	4	3	3	4	4
Database Access	4	5	4	4	3
Graphics	3	2	1	3	3
Help Screens	4	1	1	2	4
Hypertext	5	3	1	1	1
Average Score	4.17	2.83	1.83	2.67	3.17

Rating Scale: 1 = Poor
2 = Fair
3 = Average
4 = Good
5 = Very Good

CONCLUSION

As a result of our research during the Phase II portion of this project, we recommend that 1st Class Hypertext be utilized in a Phase III study. This study should focus on the continuation and combination of the NAPSAC and PRAISE prototypes.

In reviewing all of the shells, 1st Class Hypertext consistently ranked higher than the other shells. Its friendly developer and user interface, database capabilities, and advanced hypertext features are just a few of the attributes that set this expert system shell apart from the rest of the pack. All rankings in the evaluation criteria table have resulted in 1st Class Hypertext being rated as a solid "good", with its closest competitor ranking just slightly above "average".

Another feature of 1st Class Hypertext is its ability to fit into the overall long range plans for SPDMS II. This will not only benefit NASA in the photo classification and retrieval process, but will also make available an expert system shell that can be fully utilized by non-technical personnel. In summary, 1st Class Hypertext will provide the necessary tools to develop a real-time photo classification and retrieval system that meets the criteria and recommendations as set forth in the Phase I prototypes.

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APPENDIX I

Summary of Phase I NAPSAC and PRAISE Project Reports

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Summary of Phase I NAPSAC and PRAISE Project Reports

by

Fred Damiano & Paige Leone

Prepared for
Dr. James Ragusa
MAN 6908
NASA Directed Independent Study
February 5, 1990

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NAPSAC (NASA Photo System to Aid in Classification)

Summary of Prototype Research Effort

The NAPSAC expert system prototype demonstrated that an expert system is a viable solution to the current photograph classification problem. The NAPSAC Project Team felt that, in the future, all NASA photographs could be classified consistently and efficiently by using an expert system.

Expert System Benefits

1. A higher percent of photographs will be retrievable due to a better classification system (Goal 100 percent).

2. It will be easier for an inexperienced classifier to accurately classify pictures.

3. Less time will be spent "pondering" how to classify pictures.

4. It will help to eliminate the current terminology problem.

Concerns

1. One of the crucial elements of the proposed system is the acceptance of the new photograph documentation form (SSPSPDL) which will be attached to the photograph envelope.

2. Two paths are necessary for classification; one path to complete the classification of photographs using the SPDL (old form), and a second path allowing for an in-depth and consistent classification based upon the SSPSPDL (new form).

3. Need to address the classification of pictures of NASA facilities.

Problems

The primary problems in the prototype development were the limitation of the PC Easy software shell and the interface to dBase.

1. The inability to hold large rules without impeding response time and program development.

2. The absence of on-screen validation techniques.

3. The need to send each field to the data base regardless of

whether they included data or null values.

4. The inability to set one field equal to another.

5. The non-descriptive PC Easy error messages.

6. A substantial amount of data is repeated in the database.

Recommendations of NAPSAC Project Team

It is important that before any further system development begins, a new expert system shell is acquired that will compensate for the shortcomings listed above. In addition, a graphics program needs to be acquired that will allow for the development or importation of drawings into the help screens. A pilot program should be implemented with Lockheed to test a total classification and retrieval system to be used in a real-time environment.

PRAISE (Photo Retrieval And Identification System Expert)

Summary of Prototype Research Effort

The results of the prototype project revealed that PRAISE is a good candidate for an expert system. Overall, the PRAISE expert system would be an initial step in enhancing the SPC photographic quality assurance program. Photographs will continue to be an integral part of vehicle processing at KSC, therefore, PRAISE would be the first phase of implementation to a more efficient photo retrieval process.

Expert System Benefits

1. PRAISE would provide a useful system in retrieving closeout photos on short turn-around requirements for vehicle processing.

2. Lockheed would have a documented flow procedure for others within the organization to assist customers with retrieving photos.

3. This method of retrieving photos will allow for any customer or employee to retrieve the appropriate photo for themselves and possibly enhance the overall productivity of the Data Center.

4. The creation of a uniform classification and retrieval system.

5. The cost-benefit analysis has substantiated that the use of a photo retrieval system is economically and financially advantageous.

6. The hardware for implementing the interface between Lockheed and TGS is already in place.

Concerns

1. There are currently over seven million photographs to place on a database, in addition to the thousands that will continue to be taken each year in the future. Fast access to the information is a primary requirement of the retrieval process. The large volume of photos also creates a storage space problem.

2. The use of dBase III would prove to be ineffective and restrictive in a real-time implementation of PRAISE.

3. There is currently no consistent procedure for classifying photos.

Problems

The primary problems in the prototype development were the limitation of the PC Easy software shell and the interface to dBase.

1. The inability to select more than one field per record from the database.

2. The prototype expert system lacks built-in intelligence. For instance, if the shuttle mission number is known, there is no need to ask for information relating to the orbiter name since this can be derived through the mission number.

3. The commands available to retrieve data from the database are restrictive (not very powerful).

4. The retrieval of data from the database is inordinately slow.

Recommendations of PRAISE Project Team

The tools and technology used to solve the business problem at hand for the entire project beyond the prototype should be investigated. The PRAISE prototype provides a starting point for this investigation. A Phase II study for determining the viability of an operational system would have to address the problems and

concerns listed above. In addition, a PRAISE implementation would require the use of laser optics, imaging technology, and an object-oriented approach.

Conclusions Reached by the Phase II Project Team

1. Additional research and development should be undertaken to pursue the goal of combining the classification and retrieval capabilities into one expert system.

2. The Phase II research effort should be focused on identifying a new expert system shell and a database package that can handle the large volume of NASA photographs.

3. The new expert system shell must receive high ratings in speed, data base integration, data validation, and ease of use.

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NASA-Public Affairs-A

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Final Report

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INTRODUCTION
and
TABLE OF CONTENTS

This document represents the final report for Project 2A of NASA KSC Grant NAG 10-0058 (NASA-Public Affairs-A, UCF 11-28-201). This document was originally distributed to NASA as Briefing, 20 February 1990. There are four sections to this report as follows:

Section 1 Overhead Transparencies for Briefing.

Section 2 Report on Recommendations to NASA KSC Public Affairs Office.

This extensive report represents the material promised under NASA KSC Grant NAG 10-0058 Project 2A.

Section 3 A manuscript submitted to DATABASE Magazine.

This manuscript is non-technical and points out the advantages of systems like those reported in Section 2.

Section 4 A manuscript submitted to 16th Very Large Data Base Conference.

This manuscript is somewhat technical and provides a description of a prototype system planned for NASA KSC public Affairs.

Section 1

Overhead Transparencies for Briefing

NASA

Intelligent Interactive High Speed Data Search Systems

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Brief Statement of Objectives:

May 1989 - October 1989:

Using NASA KSC Public Affairs data, evaluate SPIRIT hypertext system and appropriate computer hardware in regard to automating the manner in which NASA KSC Public Affairs personnel obtain answers to media questions.

Cooperative Agreement:

As an integral part of the Automated Launch Operations Information System, research a system capable of high-speed search of very large text data bases in order to (1) produce answers to questions expressed in natural language, and (2) generate summaries of the data base information.

Outline of 15-minute Presentation

Major Activities		Slide Number
Obtain and Install SPIRIT (done)	SPIRIT Features	3
	SPIRIT Sample Query	4
Information Seeking Task (done)	Travel	5
	Students Hired	6
	Prototype Demonstration	7 a, b, c
Evaluation of SPIRIT (done)	Evaluation of SPIRIT vs. Human Search	8, 9
	Text Data Base Creation Time and Cost	10
Research Papers (ongoing)	Technology Transfer	11
Preparations for Long-term Objectives (underway)	Practical and Research Concerns	12

5

S.P.I.R.I.T.

Syntactic and Probabilistic Indexation and Retrieval of Information in Texts

Product of Systex Company
(founded in 1979)

Main Features

- **Automatic** indexing of text using both a linguistic analysis and a probabilistic model.
- Queries in **full** natural language.
- Answer text ranked according to query relevance.
- Hypertext browsing from a page of text to other relevant pages of text, and from one document to other relevant documents.
- End-user interface and help assistance.
- Sophisticated linguistic processing in languages such as French, English and Arabic.
- A dictionary covering the greater part of each language.
- Large database capability. For example, it is more than 100 times as large as the set of documents currently used by NASA KSC Public Affairs.
- Availability on various hardware systems ranging from the IBM PC and the Unix micro and minicomputers to various mainframes.

Sample Query

Shuttle Data Base: 5000 documents, each a paragraph in the shuttle manual

<1> : How long does the payload crew go through training before a launch?

EMPTY WORDS: how, does, the, through, before, a.
KEY WORDS: long, does, payload, crew, go, training, launch.

CLASSES	NB DOCS	KEY WORDS
1	1	Payload-crew, training, launch
2	2	payload-crew, training
3	1	long, payload, crew, training, launch
4	1	long, payload, crew, training
5	1	payload, crew, go, launch
6	1	does, go, launch
7	1	does, payload, training
8	1	does, crew, go
9	1	crew, go, training
10	1	long, payload, training
11	1	long, does, crew
12	1	does, payload, launch
13	3	payload, training, launch
14	2	crew, go, launch
15	1	does, crew, launch
16	2	crew, training, launch
17	3	payload, crew, go
18	17	payload, crew, training
19	2	long, crew, launch

DOC 3386 BASE : doc 3386 NCP:0/CPI:1/NBI:1 +18 1K/1K
IDENTIFIER : doc 3386
TEXT..... :
Training requirements depend on the complexity of both the individual instruments and the integrated payload. The investigator helps determine training requirements for his instrument and participates in training the payload specialists and support personnel who may operate equipment, monitor data or assist in troubleshooting. Investigators who participate in such activities also require indoctrination and training in practices and equipment operation. Payload crew training currently begins 1.5 to two years before launch and continues through launch. Training on individual experiments and experiment instruments is normally scheduled before payload integration, which begins approximately one year before launch.

Travel

- Trip to Paris, France.
  Funded by: NASA KSC
  Purpose: Visit the SYSTEX Company (developers of SPIRIT) for demonstration of the system.
  NASA KSC Benefit: (a) SPIRIT obtained for demonstration purposes.
  (b) Columbus User Information System data base from the European Space Agency obtained as SPIRIT data base.

- Trip to International Workshop on Expert Systems and their Applications, Avignon, France
  Funded by: UCF Division of Sponsored Research
  Purpose: Present paper concerning generating answers from text for queries expressed in natural language.
  NASA KSC Benefit: Learned about CALYPSO (French IBM product) which claims to automate text-searching problems.

- Trip to Fourth Rocky Mountain Conference on AI, Denver, Colorado
  Funded by: UCF Division of Sponsored Research (50%)
  UCF Department of Computer Science (50%)
  Purpose: Present two papers on automated abstracting and automated summarization of text data.
  NASA KSC benefit: Contacted through the conference by IBM's Los Angeles Scientific Center in regard to their development of a natural language text understanding system, the NewsSelector Project.

- Trip to First Annual Conference of the International Association of Knowledge Engineers, College Park, Maryland.
  Funded by: NASA KSC
  Purpose: (a) Attend Natural Language Parser Design Tutorial (unfortunately cancelled at last minute).
  (b) Present Expert Systems paper concerning the matching of equipment problems (stated in natural language) with troubleshooting symptoms (sated in natural language).
  NASA KSC benefit: (a) Exposure to NASA projects at Goddard Space Flight Center.
  (b) Learned about QUEST (Dow Jones product) which interrogates news stories or business articles.

- Trip to Hypertext '89 Conference, Pittsburg, Pennsylvania.
  Funded by: NASA KSC
  Purpose: Attend tutorials on information retrieval.
  NASA-KSC Benefit: Learned about related research at University of Massachusetts, Cornell University and Carnegie Mellon University.

Students Hired

Sandhya Chandarlapaty (graduate)

- Conversion of retrieval text to thematic role conceptual format
- Looking at parallel parsing algorithms and Prolog environments

Gloria Corbet (undergraduate)

- Q/A using thematic role conceptual format
- Examination of sentences in shuttle manual (class project)

7a

Demonstration

- SPIRIT
  - Enter Query
  - Relevant Text
- Question/Answer
  - Relevant text stored in conceptual format
  - Answer built from portions of relevant text

(7b)

NATURAL LANGUAGE QUERY ON THE SHUTTLE BASE

<1> : When does NASA select candidates?
EMPTY WORDS : does.
KEY WORDS : When, N.A.S.A., select, candidates.

CLASSES	NB DOCS	KEY-WORDS
1	1	select-candidates,N.A.S.A..
2	4	N.A.S.A.-select.
3	1	N.A.S.A.,select,candidates.
4	2	select,candidates.
5	2	When,N.A.S.A..
6	17	When,select.
7	9	N.A.S.A.,select.
8	2	candidates.
9	89	When.
10	118	N.A.S.A..

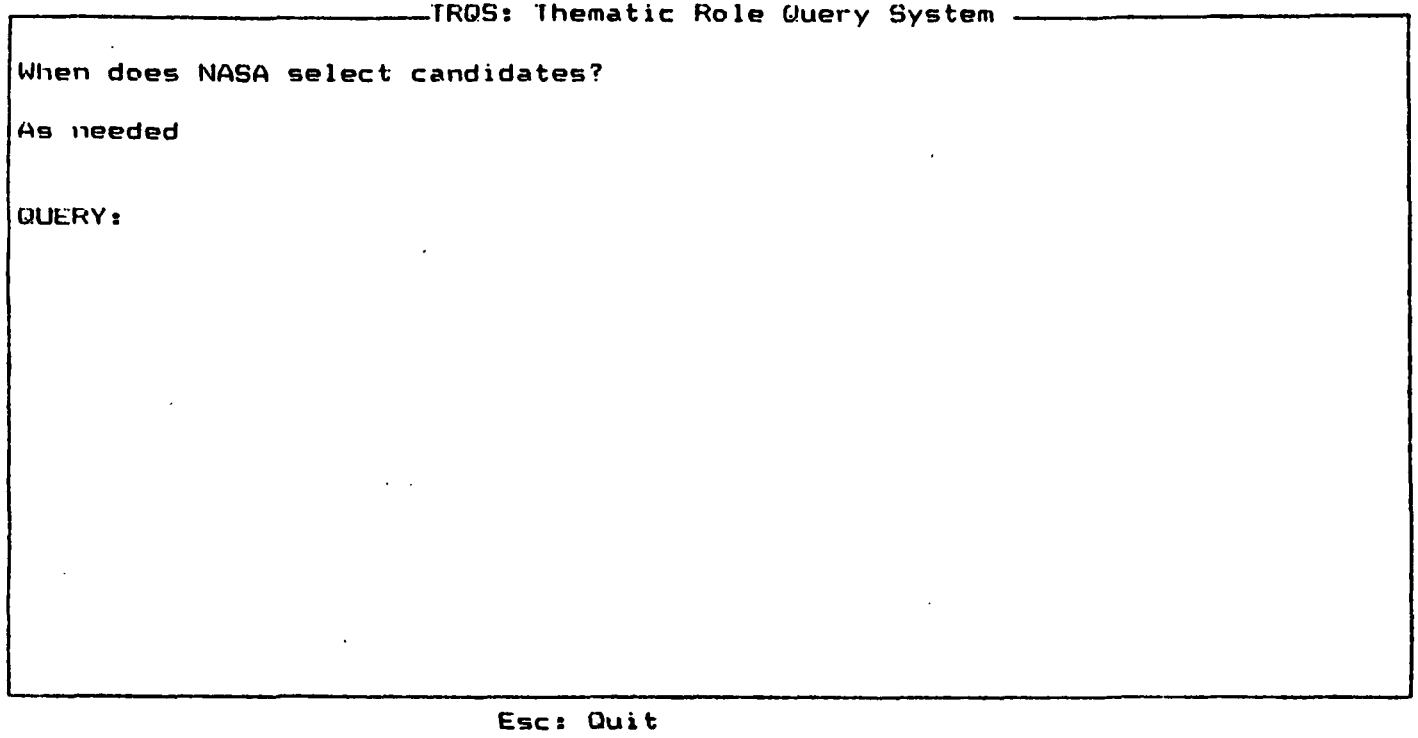
BOTTOM OF LIST

DOC 4011 BASE : doc 4011 NCP:0/CPI:1/NBI:1 +18 1K/1K
IDENTIFIER. : doc 4011
TEXT..... :

The astronaut candidate program is an ongoing and NASA accepts applications from qualified individuals -- from both civilian and military walks of life -- on a continuing basis, selecting candidates as needed for the rigorous, 1-year training program directed by JSC. Upon completing the course, successful candidates become regular members of the astronaut corps. Usually they are eligible for a flight assignment about 1 year after completing the basic training program.

BOTTOM OF DOCUMENT

(7c)


TRQS: Thematic Role Query System
When does NASA select candidates?
As needed
QUERY:
Esc: Quit

Evaluation of Shuttle Questions

SPIRIT vs. Human Search

QUESTIONS:

1. What are the dimensions of the main engine at the nozzle exit?
2. How much does each solid rocket booster weigh at launch?
3. What is the peak flow rate of water on the solid rocket boosters (pre-liftoff and post-liftoff systems)?
4. How long does the payload crew go through training before a launch?
5. What is the inflation agent in the landing gear tires?
6. How many people were killed when the Challenger blew up?

ANSWERS:

1. 14 feet long and 7.5 feet wide. Page 199.
2. 3,300,000 pounds. Page 35.
3. 900,000 gallons per minute nine seconds after liftoff. Page 901.
4. 1.5 to 2.0 years. Page 939.
5. Gaseous nitrogen. Page 489.
6. 7 people were killed in the STS 51-L launch. Page 118.

Comparison

SPIRIT

QUESTION	TIME TO FIND ANSWER (approximate times)	PARAGRAPHS READ OR SKIMMED
1	3-4 minutes	13 / 245 paragraphs
2	3-4 minutes	11 / 167 paragraphs
3	30 sec - 1 minute	1 / 133 paragraphs
4	30 sec - 1 minute	1 / 43 paragraphs
5	30 sec - 1 minute	1 / 143 paragraphs
6	30 sec - 1 minute	1 / 130 paragraphs

Human Search

QUESTION	TIME TO FIND ANSWER (approximate times)	PARAGRAPHS READ OR SKIMMED
1	30 minutes	35 paragraphs
2	1-2 minutes	3 paragraphs
3	1 hour ++ (gave up)	24 pages x 8 paragraphs per page Could not find the answer
4	6 minutes	24 paragraphs
5	20 minutes	36 paragraphs
6	12 minutes	15 paragraphs

TIME ESTIMATES for Creating a SPIRIT Data Base

- **Examine documents / create list of files for marking system.**
  Depends on the number of documents. Approximately fifteen minutes to two hours.

- **Run CONVERT or CONVERT2 to create the marked database.**
  Depends entirely on the number of documents and the speed of the computer. About one hour, 35 minutes for the shuttle manual on an IBM/XT PC, using hard drives for all I/O. It is recommended that at least an AT or compatible be used for faster processing along with hard drives for retrieval of the documents and storage of the output file.

- **Send the marked database from the PC to the mainframe.**
  Depends on the size of the database and the baud rate of the communication link. Once the software is set up, it takes about five to thirty minutes.

- **Enter SPIRIT and index the database.**
  Also very dependent on the size of the database and possibly on the number of users on the mainframe. The entire shuttle manual took about three hours, thirty minutes during a period of time when the mainframe had normal use. The computer usage cost was $280.00.

- **Authorize the user to access the new database.**
  About three to five minutes, regardless of the database.

Note: It is estimated that the number of man-hours required to get the shuttle manual database created was about seven hours, thirty minutes.

Technology Transfer

Research Papers

✔ 1. *New Directions for Microcomputer-based Hypertext Systems*
by Kenneth Ray and James R. Driscoll

Submitted to DATABASE magazine (papers for the librarian professional)

✔ 2.
A Portable Natural Language Query Interface for Databases Containing Large Amounts of Textual Data
by James R. Driscoll

Submitted to Conference on Very Large Data Bases (technical papers)

Technical Manuals

✔ 1. Instruction Manual for Creating Databases with the SPIRIT System

✔ 2. Research Report for Recommendations to NASA KSC Public Affairs

Practical and Research Concerns

- When documents retrieved by SPIRIT do not answer a query, we are looking at why they do not.
- PC version of SPIRIT-like system under development for another project.
- Linguistic research underway for a conceptual format for English text to enable Q/A and Summarization.
- Considering complete English dictionary and Thesaurus storage in electronic form.
- Looking at parallel processing, concurrent programming, and data compression techniques for speed considerations.

Section 2

Report on Recommendations to NASA KSC Public Affairs Office

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p.34
N91-70581

INSTRUCTION MANUAL FOR CREATING DATABASES WITH THE SPIRIT SYSTEM

PREPARED FOR NASA KSC PUBLIC AFFAIRS OFFICE

DECEMBER 1989

Written by Mark A. Clark

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I. Instructions for IBM/PC Software Modules.

A. Introduction:

Several software modules have been created to aid in producing the required marked database to be indexed by the SPIRIT system. The modules were written in Turbo C and Turbo Pascal on an IBM/XT. They will run on any IBM/XT, AT, or any compatible computer. The Turbo C or Turbo Pascal compilers are not needed, as the modules are in an executable form. Even the Turbo Pascal Database Toolbox modules are included since they are used in some of the Pascal programs. All files are contained on the 5 1/4" disk labeled NASAPROJECT. A directory of this disk appears in figure 14 at the end of this instructional manual. All that is necessary to use the modules is to make the drive that NASAPROJECT is in the current drive. Then enter the name of the module desired. For example, to use the CONVERT2 program, simply type in "convert2" and hit enter at the dos prompt. Each module will prompt the user for certain input. An explanation for each module is written below.

With regard to SPIRIT, the modules most often used in database preparation are CONVERT (or CONVERT2), and FILEVIEW.

B. Explanations of modules:

(c) means written in Turbo C
(pas) means written in Turbo Pascal

CONVERT(pas)-Used for marking documents for the SPIRIT system. Same as CONVERT2 but not as many features (can't override the automatic marking process). Follow the prompts. See CONVERT2.

CONVERT2(pas)-This program takes a list of files and formats them for the SPIRIT database system. It will remove garbage control characters, and is intended to be used on documents created by WordPerfect or Wordstar THAT ARE SAVED AS AN ASCII TEXT FILE. It puts in the special document markers between each paragraph, and formats a line to a maximum of LINELEN characters. One can specify whether or not right justification is desired. In the input file, which is a list of filenames, there should be only one filename per line (drive and pathnames are allowed to proceed the filename in the usual dos manner). Each line should end with a carriage return, NOT a linefeed. A filename proceeded by a # (like #a:myfile.doc) will be treated as a single document. This is allowed for special parts of the document created where it is desired to override the automatic marking system. If the # character is not present, each paragraph (if more than 4 lines) will be treated as a document in the output. All files in the list of filenames will be concatenated into one long file for output. The input file (list of filenames) can be created with

any simple text editor. The Turbo editors are fine. An example of such an input file can be found in the file SHUTTLE.LST on this disk. One can also create the input file as the program is running, and it will save it for later use. The LINELEN constant has been set to 76, but can be changed by changing its value in the code and recompiling. This was done as a safety feature since SPIRIT restricts its lines to no more than 78 characters. CONVERT2 expects paragraphs to end with a linefeed or carriage return. The user might want to look at his file with FILEVIEW to make sure this is the case. Otherwise CONVERT2 will most likely not work as intended. When giving the name of the output file, make sure there is enough storage room available for the output to be saved. Follow the prompts for what to enter.

REMARK: With regard to the marked documents SPIRIT expects, CONVERT2 creates documents with two fields, an identifier field and a text field in every document (see section II-C3, "Document markers and document preparation").

FARHEAP(c)-Utility that returns the number of bytes left in the farheap.

FILEVIEW(pas)-Use this to look at text files created by wordprocessors to see what special characters are in the file. The three most common are 10 (carriage return), 13 (linefeed), and 26 (end of file). Special characters are set out between vertical bars so they can be "seen" in the document. Consult an ASCII table if necessary. Use this utility to look at the file BEFORE trying to use CONVERT or CONVERT2.

FREQCNT(c)-Produces frequency count of words in a single text file. Creates "outfile.doc" (alphabetic list) and "outfile.frq" (by order of frequency) in the current directory. Follow prompts.

MAKEALPH(c)-Creates an alphabetic list of words and their frequencies from many documents. Enter input files as prompted. Enter quit when there are no more files. Output stored in "b:outfile.doc".

MAKEFREQ(c)-Makes a frequency list from an alphabetic list. Each line must have just "integer, string". Usage of the file created by MAKEALPH or MARK is an option.

MANYDOCS(c)-Same as FREQCNT, but it works on many documents at once. Enter documents as prompted, quit if no more documents to input. Output saved in "outfile.doc" (alphabetic list) and "outfile.frq" (frequency list) in the current directory.

MARK(pas)-Program takes a list of files and indexes all the files in that list. It then creates an alphabetic list of all words that appear in all the files with their frequency count. This program contains a list of 100 most common words that are not included in the list created. It uses the Turbo Pascal Database

Toolbox B+ trees for efficiency. Enter index to be created, input file (list of files to examine), and then the name of the alphabetic list to be made.

MERGETWO(c)-Merges two alphabetic lists into one list. Each input file must have "integer, string" per line (such as the files created by MARK or MAKEALPH). Enter first source file, second source file, and destination file at the prompts.

QUICKFREQ(pas)-Program takes alphabetic list (such as one created by MARK) and converts it to a list ordered by frequency counts. Again, each line of the input file should have "integer, string". Uses quicksort routines from the Turbo Pascal Database Toolbox. This is the recommended module to use to create a frequency list of words, but first use MARK to create the alphabetic list.

SHUTTLE.LST(Not a module)-An example of the type of input file that is expected for the module CONVERT2.

TRUN(c)-Utility can be used to truncate a long list after a printer jam and one wants to continue printing, but does not want to start over.

II. Instructions for using SPIRIT.

A. Introduction:

Most documents created at the NASA Kennedy Space Center are created on IBM-PC compatible computers such as the Compac Deskpro 386 using Wordstar 2000. However, the shuttle manual was created by Rockwell using WordPerfect. Both of these wordprocessors have the ability to save a document as an ASCII text file which is virtually free from the headers and control characters that make text processing difficult.

It will be assumed that one already has created all the documents that one is going to place in the database before starting this task of getting the database into SPIRIT. SPIRIT (Syntactic and Probabilistic Indexation and Retrieval of Information in Texts) is a commercial software product that runs on an IBM mainframe in a VM/CMS operating environment. Since the NASA KSC Public Affairs Office already does its wordprocessing on the PC, the decision was made to do all the text processing needed for SPIRIT on the PC. Afterwards, the database would be sent from the PC to the mainframe ready for SPIRIT to index.

In this manual, it is assumed there is a communication link between the PC (in this case it is connected to a LAN) and the

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IBM mainframe (in this case an IBM4381). If this communication link is not present, the user will need to find another method for getting the file to the mainframe.

First, the steps taken on the PC are described, then the steps taken on the mainframe. As the steps taken on the mainframe are described, the necessary features of SPIRIT used to prepare a database are mentioned. Finally, some other auxiliary features of SPIRIT are described that are not needed when creating the database.

B. Steps to create a database.

1. Examine documents/create list of files for the marking system

To examine the documents, use the DOS command TYPE, such as "type myfile.doc". However, this method has the drawback that control and special characters are not revealed. Use the FILEVIEW program to see what special characters are being used. Any editing must be done with an editor that will save the document as an ASCII text file.

Creating the list of files can be done with this same editor, or with one of the Turbo editors. It is at this point that one should decide what documents should be automatically marked and what documents should be kept in its entirety. One should also experiment with the CONVERT programs to see if they will work as the user expects. Remember, CONVERT is expecting linefeeds or carriage returns to mark the end of a paragraph, with no other special characters used for this purpose.

2. Run CONVERT or CONVERT2 to create the marked database.

Once the user is satisfied with the way the documents will be separated and marked, it is time to run either of the CONVERT programs to create the database.

If the document is prepared in another way, please see section II-C3, "Document markers and document preparation". The user must prepare and mark the documents properly before trying to index them. The database can be prepared from a variety of sources, even the vanilla editor in SPIRIT, but must be laid out with the proper markers for SPIRIT to use.

3. Send the marked database from the pc to the mainframe.

The explanations in this step are geared towards the equipment at the University of Central Florida (UCF). It is

expected this procedure will vary at other sites. If document creation and marking is done on the mainframe, then this step is unnecessary.

Use the Local Area Network (lan) terminal in the faculty I and R lab, or one of two lan terminals in CCII-106 that allow one to log on the lan and mainframe simultaneously. Make sure there is adequate room on a mainframe disk to store the base. Make drive "a" the current drive on the lan. Then enter:

a>SEND <lanfilename> <mainframefilename> FIIN A (ASCII CRLF

Case of letters is not important. The filename is arbitrary, but SPIRIT expects a filetype of FIIN. "A" is just the drive specification. At this point, the base should be on the mainframe and one can log off the lan.

SPIRIT expects the base file (which will often be referred to as the FIIN file, because the index file SPIRIT creates has a filetype of BASE) to be of fixed length records of 80 characters. SEND has created a variable record length file which should now be changed to fixed length. To change the file, enter:

COPYFILE <mainframename> FIIN A (RECFM F LRECL 80

Do a directory to make sure the FIIN file is now F80. This will be indicated by F and 80 in two of the columns of the directory. For those not familiar with CMS commands, one way to get a directory of files on disk D is to enter "fl * * d" from CMS. When done hit pf3 to quit. See a book of CMS commands for more details.

Now an important remark about base names used in SPIRIT. The filename given to the FIIN file becomes the (data)base name throughout SPIRIT, unless later changed. When SPIRIT asks for the name of the base, it means the filename before "FIIN <filemode>". If the input file is SHUTTLE FIIN D, then the base name would be SHUTTLE.

4. Enter SPIRIT and index the database.

A profile called PROFI should be executed to set up disks A, B, C, D, and G for the SPIRIT system. Enter "PROFI" to run it. This profile also moves the old A disk to E.

Move the FIIN file to drive D using "COPY <filename> FIIN E <filename> FIIN D". If this is done before running PROFI, replace E with filemode A. This will give the user two copies of the FIIN file. If only one copy of this file is desired, run the profile PROFI first before sending the file to the mainframe. Then just send the file to disk D instead of disk A.

Now enter SPIRIT by entering "$PROFX". The main menu will appear (fig. 1). Select CREATE A DATABASE by entering "2". A table will appear with some words in French (fig. 3). For most purposes, only two fields need be declared, identifier and text. The field type (type du champ) must be FACT for the document identifier, and TEXT for the text field. Leave the video field (champ video) as N. Leave the identifier field (champ ident) as N, EXCEPT the identifier field, which must have the letter "o" or "O". The "LG DE LA QUESTION" field is for the query grid. Enter any number such as 80.

When the table has been completed, move the cursor to the bottom center of the screen, and enter "s". For some more details on filling in this table, see section II-C3, "Document markers and document preparation". The example in figure 3 will suffice for most purely textual databases.

Next, one will see SPIRIT creating messages as it creates the base (fig. 4). Success at each step is shown by a return code of 0 (RC=0). There will be about two screens of processing messages before the base is created. When SPIRIT is finished indexing, a message appears as a reminder to give the user access to the base. Hit enter to return to the main menu.

5. Authorize the user to access the new database.

To authorize the user to access the database, choose MANAGEMENT UTILITIES by entering "g" at the main menu. Then from the UTILITIES menu (fig. 2), choose 1, PROFILE MANAGER. The user will be asked several questions that are still in French (hopefully, this will be corrected in later versions). Enter these answers to the questions (user answers will be in capital letters):

```
STEPS TO ADD A DATABASE NAME TO THE LIST OF BASES:
Choix (Tulib, Dpb,.....)    :T (fig. 5)
Commande                    :M (for modify or update)
Type du profil              :U (for user)
Profil a modifier           :SPIRIT (name of the profile that
                             contains information for the bases)
Voulez-vous voir.....       :F
Nro de variable ....        :12 (the choice to modify the list of
                             bases)
Ajout,....                  :<enter base name> (must be same name
                             that the FIIN file uses, see NOTE#1)
* more than one base name can be added to the list at this point
by separating base names with a semicolon (;).
Ajout (suite)               :<enter>
Suppression                 :<enter>
Voulez-vous voir la liste..:<enter>
```

To end and save the changes, enter "F" at the prompt "Nro de variable a modifier" (fig. 6). Continue to enter "F" until being returned to the UTILITIES menu (a total of four times). "F" is for "fin", which is French for "end". Enter "F" again to return to the main menu. The database is now ready to query.

Once the database name has been put into the list of databases to access, it will stay there unless the user removes it. Therefore, if the base is reindexed, this step does not have to be repeated. The name of the base can even be in the list when the base no longer exists. In this case, if the base that does not exist is requested (fig. 8), an error message will result. If another base is not desired when figure 8 appears, enter "fin" to quit.

To remove a database name from the list of bases, follow the same steps as above in "STEPS TO ADD A DATABASE NAME TO THE LIST OF BASES", EXCEPT for the following:

Ajout,.... :<enter> (unless of course there is another database name to be added)
Ajout (suite) :<enter>
Suppression :<enter a base name to delete>
* note: more than one base name can be deleted at a time by separating names by a semicolon (;).

All other steps are the same. End and save changes in the same manner as shown above.

C. Features of SPIRIT.

1. Vanilla editor.

The main menu choice one (SAVING AND STORING DOCUMENTS) takes the user to the vanilla editor which is described in more details below.

The most commonly used function keys are defined as follows:
pf1=help menu
pf3=file(save and quit)
pf4=tab key
pf7=back a page
pf8=forward a page
pf11=split/join
pf12=cursor home (toggles cursor between command line and text).

For a complete list, enter "q pf" on the command line.

The following is a list of the more commonly used features of this editor.

ADD LINES

Move cursor to numeric field in left column of line above where additional lines are desired. Enter a number followed by "a" and "enter" (or just "a" and "enter" for a single blank line) to enter as many blank lines as desired. Example: to insert 3 blank lines between lines 7 and 8, go to numeric field of line 7, type 3a, and hit enter.

DELETE LINES

Move the cursor in the numeric field on the left column of the screen to the line where deletion of some lines is desired. Enter a number followed by "d" and "enter" (or just "d" and "enter" to delete a single line) to delete as many lines as desired. Example: to delete lines 2,3, and 4, go to numeric field of line 2, type 3d, and hit enter.

DELETE A BLOCK (a block is two or more adjacent lines)

Block the text with "dd" in the numeric field of the first line of the block, and a "dd" in the numeric field of the last line of the block. Hit enter and the block will be deleted.

MOVE A BLOCK

Block the text with "mm" in the numeric field of the first line of the block, and a "mm" in the numeric field of the last line of the block. Move the cursor to the line just above where the text is to be moved, and put "f" (for following) in the numeric field of that line. Hit enter and the block will be moved. To move a single line, put "m" beside the line to be moved, and move the cursor to the line just above where the line is to be inserted. Then put "f" in the numeric field of that line, and hit enter.

COPY A BLOCK

Follow the same instructions for MOVE A BLOCK. Note however that "mm" should be replaced with "cc", and "m" with "c" when copying a single line.

STRING SEARCHES

To obtain all the lines of the file that contain at least one occurrence of a string, enter "ALL /<string>/" on the command line. As usual, hit the enter key when entering commands on the command line.

QUIT AND SAVE

Hit pf3, or enter "FILE" on the command line.

QUIT WITHOUT SAVING CHANGES

Enter "QQUIT" on the command line.

CURSOR HOME

Hitting "enter" when the cursor is in the text area will home the cursor to the command line. Also, pf12 toggles the cursor between the command line and the text.

SHIFT SCREEN LEFT OR RIGHT

For text that does not fit completely in the current window, there is the ability to shift the screen left or right. Enter "LEFT <number>" or "RIGHT <number>" on the command line to shift the screen left or right <number> characters.

REMARKS

The backspace and delete keys operate in the text as one would expect. To see less frequently used commands not mentioned here, hit pf1 to obtain help. To get specific help on a known command, enter "HELP <commandname>" on the command line.

The SPIRIT vanilla editor is useful for making minor changes in the documents, or for deleting documents. However, it is not recommended for making major changes or updates to the database due to its lack of features. Major changes can be made in a wordprocessor on the microcomputers and the database can be marked there for SPIRIT to use. However, one advantage of this mainframe editor is that it can handle larger files than most microcomputer based text editors. The user might need to experiment to see which editor they are most comfortable with. Regardless of which editor is used, SPIRIT must reindex the database for the changes to go in the base.

2. Natural language queries and accessing the documents.

To query the database, choose "S" (QUERY THE DATABASE) from the main menu. At the next screen (fig. 7), hit enter. Erase "***" and enter "?" for help, or "fin" to return to the main menu, but this is rarely needed.

First, the user will be given a list of bases to choose from (fig. 8). Enter the name of the base to query. This list is all the base names that one can now choose from. The BASE file must be present to access the base, otherwise this operation will not work. Another situation is that the BASE file has been created,

but the name of the base is not present in this list. This will also create a situation in which the user will not be able to access the database. See section II-B5, "Authorize the user to access the new database".

At the next step a screen telling the number of documents in the base and the date of the last update appears (fig. 10). Hit "enter" to continue.

Finally, the principal menu of the query system appears (fig. 11). Below are the descriptions of the principal menu choices.

a) QUERY or Q

This is for natural language queries on textual fields. Queries must be posed as questions (they should end with "?"). The case of the letters is not important (see fig. 11). Hit enter after typing in the question, and lists of empty and key words will appear. Hit enter to continue (generally anytime "***" appears in SPIRIT, it means hit "enter" to continue).

Next a list of classes of documents found appears with the number of documents in each class (fig. 12). Keywords are also listed for each class. SPIRIT ranks the classes by the number of hits (keywords matched) and the proximity of the keywords to each other. Keywords roughly next to each other will be separated by a hyphen (-). Keywords appearing in the same document but some distance apart, will be separated by commas. Select the classes to be shown by entering a list of numbers separated by commas.

For "What do you want to display?" the options are:
<<.....first page of the document.
< or pf7.....previous page.
doc or "d".....display another document.
end or "e" or pf3.....end this query.
stop or "s" or pf4.....stop session, return to main menu.

b) AFQUERY

This feature is for forming a natural language query on all the fields, not just the textual fields. It works the same as QUERY, just the search domain is larger.

c) CONTQ

Used to continue the previous question. Allows one to ask more than one question simultaneously, or to change the previous question slightly. The screens will look the same as in QUERY.

d) BOOL

Used for boolean queries which create a list of documents that satisfy a logical expression containing the logical operators AND, OR, and EXCEPT. The submenu options are:

doc or "d"...browse documents.
end or "e"...return to principal menu.
help.....short tutorial of boolean queries.
histo.....browse previously asked questions.
list or "l"..display document numbers that satisfy the most recent query.
listfld.....list the fields in the current base.
display.....show documents found in the current list.

Examples of boolean queries can be:
<1>: <singleword>...retrieves documents that contain <singleword>
<2>: <word1> AND <word2>...retrieves documents that contain <word1> and <word2>
<3>: <word1> OR <word2>...retrieves documents that contain <word1> or <word2>
<4>: <word1> EXCEPT <word2>...retrieves documents that contain <word1> but not <word2>
<5>: 2 AND (date:=810101)...represents result of query #2 in which the date is January 1, 1981 (words or expressions can be substituted with an integer which represents the result of that numbered query).
<6>: OR (date:=810101)...represent documents that satisfy the last query or ones in which the date is January 1, 1981 (if the question begins with a logical operator, the result of the last question is the first operand).

An operand is any logical expression between parentheses. Comparison operators on structured fields are <, >, =, <=, or >= preceded by a ":" (i.e. (date:<810101), (date:>= 810101), etc.).

An operand can also be the result of any previous query.

<7>: 1 AND 4...yields documents satisfying queries #1 and #4.
<8>: shuttle OR 5...yields documents having the word shuttle or satisfying query #5.

Order of evaluation is from right to left. OR has priority over AND and EXCEPT. Parentheses can be used to change this order of evaluation. To clarify this, "<word1> AND <word2> OR <word3> EXCEPT <word4>" means "<word1> AND ((<word2> OR <word3>) EXCEPT <word4>)" due to the default order of operations. It should also be noted that the operator AND can be left out of the expression. Any two operands not separated by an operator are assumed to be separated by AND ("cabin pressure" means "cabin AND pressure"). The boolean expression can get as complicated as one can imagine, but it is suggested that one modify the query in small steps.

```
<9>: ((shuttle (landing OR launch) site) EXCEPT night) OR
     (shuttle launch site EXCEPT (kennedy space center OR
     florida))
<10>: shuttle landing OR launch site (remember OR evaluated
                                      before AND, so no
                                      parentheses are needed)
     610 documents are selected (this message from SPIRIT)
<11>: EXCEPT night
     392 documents are selected
<12>: shuttle launch site EXCEPT (kennedy space center OR
      florida)
     126 documents are selected
<13>: OR 11
     3457 only one document is selected
```

e) DOCQ

Use to query with a document. It uses all the keywords in one document to find all related documents. SPIRIT takes all the keywords in this chosen document and finds the other documents in the base that contain at least one of these keywords. Documents are ranked by the number of keywords matched. Enter the document number with which to query. One can select the classes of documents to look at in the usual fashion. This command can be used to simulate hypertext linkages between documents.

f) ANSWER

Shows the list of documents that satisfied the last query.

g) DOC or D

Use to browse documents in the base. Enter the document number of the document to view.

h) BASE

Use to change the base the user queries (fig. 8).

i) STOP or S

Ends SPIRIT session and returns to main menu.

j) PRINT

Use to print documents if printer is set up for printing.

k) G(rid queries)

Use for queries on multiple fields. (not documented here)

l) HISTO

Use to see a list of previous questions in this session.

m) ?

Use to see a shorter summary of these commands

3. Document markers and document preparation.

An example of a marked document is figure 13. It consists of three documents (lines 1-7, lines 8-15, and lines 16-19) of two fields each.

Each document must begin with a document identifier field, and can have any additional number of fields following the identifier field. Each field begins with "$$#" on a line by itself where # is a positive integer indicating the field number. A recommended identifier field might be "DOC<docnumber>" on a line by itself. The documents follow one another without a particular separator except the identifier field. The FIIN file is therefore a sequence of field numbers followed by their content. The field numbers should be in increasing order for each document, and some of the fields can be skipped in a given document. If they are not in increasing order (say they go from 16 to 3), then this will be considered the beginning of a new document. Again, field number one must be the document identifier field.

The text line is limited to 78 characters. The file format must be fixed record length and record length of 80 (F80). Two characters are reserved by SPIRIT for the display mode.

The input file name is normalized as "<basename> FIIN <filemode>" where <filemode> is usually D.

The first part of a marked database might look like:

```
$$1                                          ----+
content of identifier field one                  |
$$2                                              |
content of field 2                               |
$$3                                              +--document 1
content of field 3                               |
$$10                                             |
content of field 10 (ok to skip some fields)     |
$$25                                             |
content of field 25                          ----+
```

```
$$1  (start of a new document)                  ----+
content of identifier field one                     |
(identifier field must be in every document)        |
$$7                                                 +--document 2
content of field 7                                  |
$$12                                                |
content of field 12                             ----+
```

For certain documents, the marker "$$" can be inconvenient. To change it, change the variable "&CSEP" of the "$SPIFORM" exec to another two character sequence.

The following are some explanations of the field definition screen which one sees when creating a database. An example is:

Field name	Abbreviation	Field Type	Video Field	Identifier Field	Length of Question
identifier	id	fact	N	o (letter)	80
date	date	date	N	N	30
last name	lnam	fact	N	N	50
first name	fnam	fact	N	N	50
address	addr	fact	N	N	100
background	bkgd	text	N	N	80

DOUBLE CHECK ANSWERS, THEN ENTER "S" TO EXIT:__

Possible choices for:
FIELD TYPE: FACT, TEXT, or DATE. (use FACT for identifier field)
VIDEO FIELD: most purposes N. O (the letter) indicates the field contains the address of a video image.
IDENTIFIER FIELD: all should be N, except the first which is O.
LENGTH OF QUESTION: length of the query criteria which is associated with the field (used to define the query grid).

4. Database updates.

Main menu choice 3 (UPDATE A DATABASE) can be used when a document is to be added to a database (inserted or appended to the end). Also, it can be used to update current documents of a database if the identifier for the database already exists. A document is created if the identifier for it does not exist in the base. The word update is used in the usual sense (i.e. add lines, delete lines, make any changes on current lines).

It is also possible to use this procedure to delete the content of a document. This can be done by deleting all the fields for that document in the input (FIIN) file, EXCEPT the identifier field (this will be the only field left in that

document). This will cause the document to be empty giving the appearance of being deleted.

When using this procedure it does not matter what files have been left on disk G, unlike when reindexing using the alternate method in section II-C6 below. It is recommended that disk G be completely erased before logging off if it is not a temp disk (see section II-C6, topic "THE WORKSPACE ON DISK G").

The procedure is as follows. Use the vanilla editor (or any editor) to make the changes to the input (FIIN) file (see section II-C1 above on the vanilla editor). Choose "3" from the main menu. Enter the base name and a letter to indicate the language of the base ("e" or "f") as prompted. The reindexing process now begins. If the base name is not yet in the list of databases to access, put it in the list before trying to use the base (see section II-B5, "Authorize the user to access the new database"). If this has already been done (probably was done after creating the base the first time), then the base should be ready to use.

If for some reason the base created has erroneous results (documents in the wrong order, document content not with proper document identifier, updates not put in, etc.), then the user MUST start over again creating the base with main menu choice 2. Certain things must be done BEFORE reindexing with this method. The reader should read "ALTERNATIVE METHOD FOR REINDEXING A DATABASE" in section II-C6 below first.

5. Database deletion.

The entire database can be deleted at once by choosing main menu choice 4 (DELETE SOME DOCUMENTS). Enter the name of the base, and a letter "e" or "f" to indicate the language of the base when prompted.

Actually what happens is that all the documents that appear in the FIIN file at that instance are deleted from the base. If no changes to the FIIN file have occurred since the last indexing, the entire collection of documents (i.e. the entire database) will be removed. If only a few documents are deleted from the FIIN file (say documents 2 and 3) before choosing 4, then the result of choosing 4 is all documents will be deleted from the base EXCEPT documents 2 and 3. Other strange occurrences result when documents are added to the FIIN file before choosing 4.

For these reasons, no changes should have been made to the FIIN file since the last indexing before choosing this option.

6. Miscellaneous features of SPIRIT.

ENTERING VM COMMANDS FROM INSIDE SPIRIT

Choose main menu choice V to do this. Then enter a VM/CMS command in the usual fashion.

EXITING SPIRIT

Choose main menu choice F to exit. Generally entering "F" at any level of SPIRIT causes an exit or quit. Also "S" and "E" are sometimes used to quit at certain levels, however "F" usually takes the user out to the greatest extent possible at that point.

ALTERNATIVE METHOD FOR REINDEXING A DATABASE

Recall that the original text of a database is stored in a file on disk D of filetype FIIN. Indexing creates four new files on D with filetypes DPB, GRIL, NBPAB, and BASE. To query the database, only the BASE file is needed. However, grid queries are not supported with just this file. Several files are created on the temp disk G during the indexing process.

If there are some problems reindexing a database after updating it, (i.e. problems using SPIRIT main menu choice 3, "UPDATE A DATABASE"), then here is another recommended technique to reindex a base:

a) Make sure disk G is completely empty. If the file CLEANG EXEC A is on the A disk, from outside SPIRIT one can enter "CLEANG" to empty the G disk. Also, one can enter "ERASE * * G1" from anywhere one can enter a VM command (see ENTERING A VM COMMAND FROM INSIDE SPIRIT in this section).

b) For the particular database name, erase the files beginning with that name and having the filetypes DPB, GRIL, NBPAB, and BASE from disk D. DO NOT ERASE THE FIIN FILE (the result of doing parts a) and b) will be like starting anew).

c) Index the database as done previously using main menu choice 2 (CREATE A DATABASE).

d) If the database name is not yet in the list of base names, add it now (see section II-B5, "Authorize the user to access the new database"). If this has already been done (which it should have if the base is being reindexed), then it does not have to be done again. Once the base name is in the list of bases, it will not leave the list unless it is deleted.

REMARK: The only operation main menu choice 3 (UPDATE A DATABASE) saves is filling in the field table again, and a few steps in the syntactic and linguistic analysis of the database.

THE WORKSPACE ON DISK G

Normally, disk G will be a temp disk that will erase itself upon logging off. IF THE DISK G IS NOT A TEMP DISK IT IS IMPORTANT THAT ONE ERASE ALL FILES ON G BEFORE INDEXING (OR BEFORE REINDEXING ANY DATABASE when not using main menu option 3). If G is not empty, SPIRIT might abort the indexing process. It is a good habit to erase G before logging out, and before indexing (or reindexing if not using option 3), PROVIDED DISK G IS A PERMANENT DISK AND NOT A TEMP DISK.

An exec called CLEANG can be used to do this FROM OUTSIDE THE SPIRIT ENVIRONMENT. Execute it by entering "CLEANG" from OUTSIDE SPIRIT (check to see if CLEANG EXEC A is on disk A). If G is a temp disk, this is not necessary WHEN LOGGING OUT, as all files on G are erased upon logging out. Disk G might still need to be cleaned if it is a temp disk AND it has some files on it AND the user is getting ready to index again. Remember, DISK G SHOULD BE EMPTY BEFORE INDEXING ANY DATABASE for the first time to be safe.

ERROR MESSAGES AND RUNTIME PROGNOSIS

A prognosis of the indexing process, along with any error messages, is found in files with the filetypes IMP1 or FERREUR on disk G. Examples are $SPIMAJQ IMP1 G for messages during creating or updating a base, and $SPISUPQ IMP1 G for messages during deletion of documents.

Another source of possible error messages is main menu choice 5 (DETECTION OF ERRORS). After choosing 5, enter the database name and language as prompted. A few messages might appear while running. Then the file $SPIGEN1 IMP1 G will come up in the vanilla editor. This file contains some of the runtime results of the last index. Also, it contains some possible spelling errors it has found, or possible words not in the SPIRIT dictionary. Hit pf3 to quit.

Since all error message files are placed on disk G, it is important that the user not erase disk G until they are sure these files are not needed. Once erased, they can only be obtained again by reindexing.

THE STATE OF A DATABASE

From the UTILITIES menu, choose 5 (LIST THE STATE OF A DATABASE). Enter the name of the base (i.e. "<basename> BASE <filemode>"). Then enter the number of records in the file, and the length of a single record as prompted. This information comes by doing a directory (i.e. the VM command "FL * * D") BEFORE getting to this point. A sample directory for one base is:

```
SAMPLE FIIN  D   F     80    10   1
SAMPLE GRIL  D   F     80     8   1
SAMPLE DPB   D   F     80     6   1
SAMPLE BASE  D   F  23472    33 190
SAMPLE NBPAB D   F     80     1   1
```

The first numeric column is the record length, the second numeric field is the number of records, and the last numeric column is the number of blocks in the file.

After answering the questions, a table will appear giving details of the fields of the base. As of this writing this is still in French. The user can page up and down with pf7 and pf8. Enter pf3 to quit from the command line.

7. A note about changes made to SPIRIT at UCF.

Four modifications have been made to SPIRIT at UCF since installing it in July of 1989.

First, some of the menus and runtime messages have been translated to English, particularly the main menu and the utility menu. Also, the runtime messages during the indexing which can be found in the exec $SPIMAJQ EXEC C, and during deletion of documents in the exec $SPISUPQ EXEC C. Other translating has been done in some of the PL1 code, but the code has not been recompiled as of this writing.

Secondly, the sort that is called while indexing databases has been replaced with SyncSort, a more efficient commercial sort routine and can handle a much larger number of records. The original sort routine could not handle the large number of records required to be sorted in the shuttle manual database (close to half a million at one point) because it did sorting in virtual memory only. SyncSort uses disk space as well as virtual memory during sorting. The use of SyncSort has decreased indexing time from between two thirds to one third of the previous indexing times.

Thirdly, for a short time disk G was changed from a temp disk to a permanent disk. This was done before indexing the shuttle manual since it was anticipated that SPIRIT would need many cylinders for the G disk. There was a limit to how many cylinders the system could obtain at any given time for a temp disk. Therefore, it was decided not to risk an abort of indexing, and G was made a permanent disk to provide more cylinders. SPIRIT does not care what type of disk G is, as long as it is available. However, it is important the user remember to clean off disk G before doing any indexing, as some of the old

files might cause the indexing process to abort (see THE WORKSPACE ON DISK G in section II-C6, "Miscellaneous features of SPIRIT").

Finally, some lines were changed in a few execs that had errors as discovered by Christian Fluhr and Tran, the developers of SPIRIT in France. Those changes will not be detailed here.

III. Database Backup and File Transfers.

A tape backup of disk D can be done by entering the following CMS commands:

1) Enter "SM IRSERV TAPE"....gets a tape drive number. Then have the operator mount the tape before doing the next command.
2) Enter "TAPE REW"....causes tape rewind.
3) Enter "TAPE DUMP * * D".
4) Enter "TAPE WTM"....writes a tape mark to separate dumps. (repeat steps 3 and 4 as needed for other drives)
5) Enter "TAPE WTM"....writes second tape mark to indicate end of tape (could use single command TAPE WTM2 after last drive or file)
6) Enter "TAPE RUN"....causes tape rewind and unload.
7) Have the operator dismount the tape.
8) Mount another tape and go to 2, or continue to step 9.
9) Enter "DET 181"....disconnects tape drive, and ends session.

To backup single files at a time, replace "* * D" in the command in step three with a specific filename, filetype, and filemode (disk).

To transfer files between mainframe accounts, enter the CMS command "SENDFILE <fn> <ft> <fm> TO <userid>" (do this from the account that the file is being sent FROM). Then log on the account that the file was sent TO and enter the CMS command "RECEIVE".

IV. Time Estimates for Creating a Database.

A. Introduction:

Most of the following time estimates were based on the database created from the September 1988 edition of the shuttle manual. It is therefore important that some facts are understood about the size of this document.

The shuttle manual after being marked contained 4902 documents, most of which were paragraphs, with a few appendices treated as an entire document. After sending it to the mainframe and converting it to a fixed record format of 80 characters, the size was 55,119 lines or 1077 blocks (4K per block). After indexing, the shuttle base file that was created took 3525 blocks of 4K each. Any reference to the time that the shuttle manual database took to create will be noted.

B. Time Estimates:

EXAMINE DOCUMENTS / CREATE A LIST OF FILES FOR THE MARKING SYSTEM

Depends on the number of documents. Approximately 15 minutes to two (or more) hours could be used, depending on the condition of the documents.

RUN CONVERT OR CONVERT2 TO CREATE THE MARKED DATABASE

Depends entirely on the number of documents and the speed of the computer. About one hour, 35 minutes was taken for the shuttle manual on an IBM/XT PC, using hard drives for all I/O. An AT or compatible should be used for faster processing, along with hard drives for retrieval of the documents and storage of the output file.

SEND THE MARKED DATABASE FROM THE PC TO THE MAINFRAME

Depends on the size of the database and the baud rate of the communication link. Once the software is set up, this task should only take about five to 30 minutes.

ENTER SPIRIT AND INDEX THE DATABASE

Again, the time for this task is very dependent upon the size of the database, and possibly on the amount of users on the mainframe. The entire shuttle manual took about three hours, 30 minutes to completely index during a period when the mainframe had moderately low use.

AUTHORIZE THE USER TO ACCESS THE NEW DATABASE

This task takes about three to five minutes, regardless of the database.

Remark: It is estimated that the actual number of hours required to get the shuttle manual database created was about seven hours, 30 minutes.

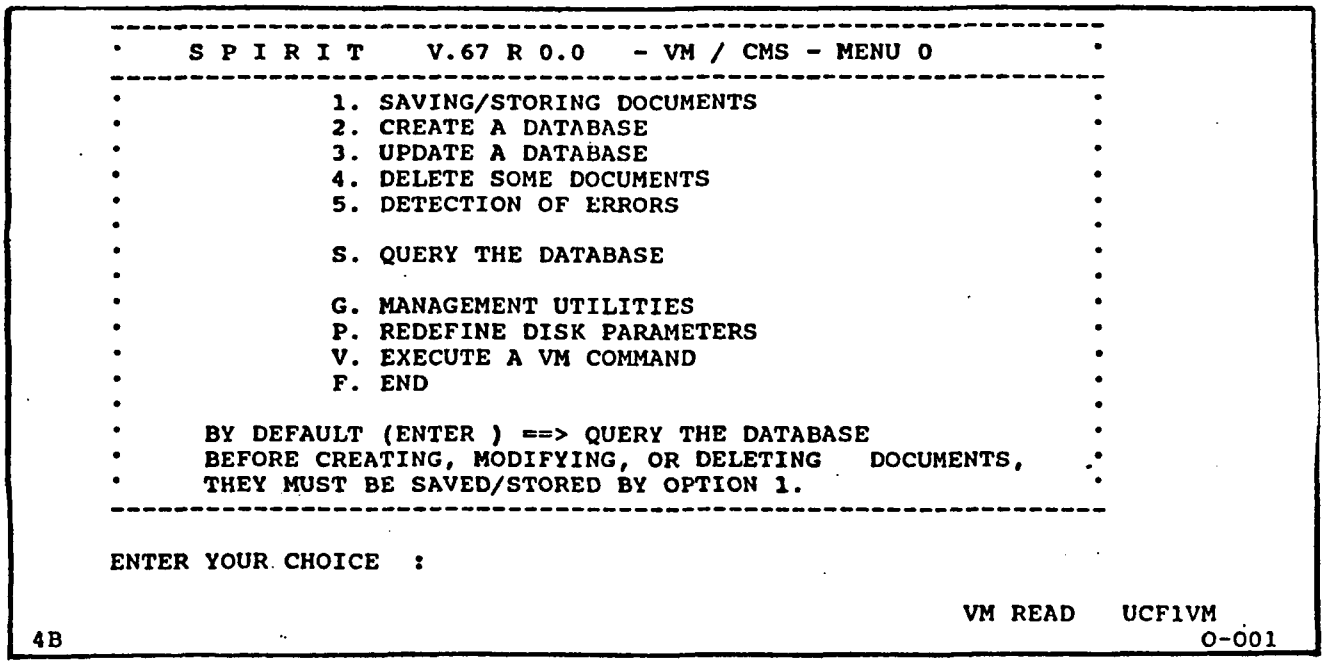

Figure #1 - SPIRIT's Main Menu

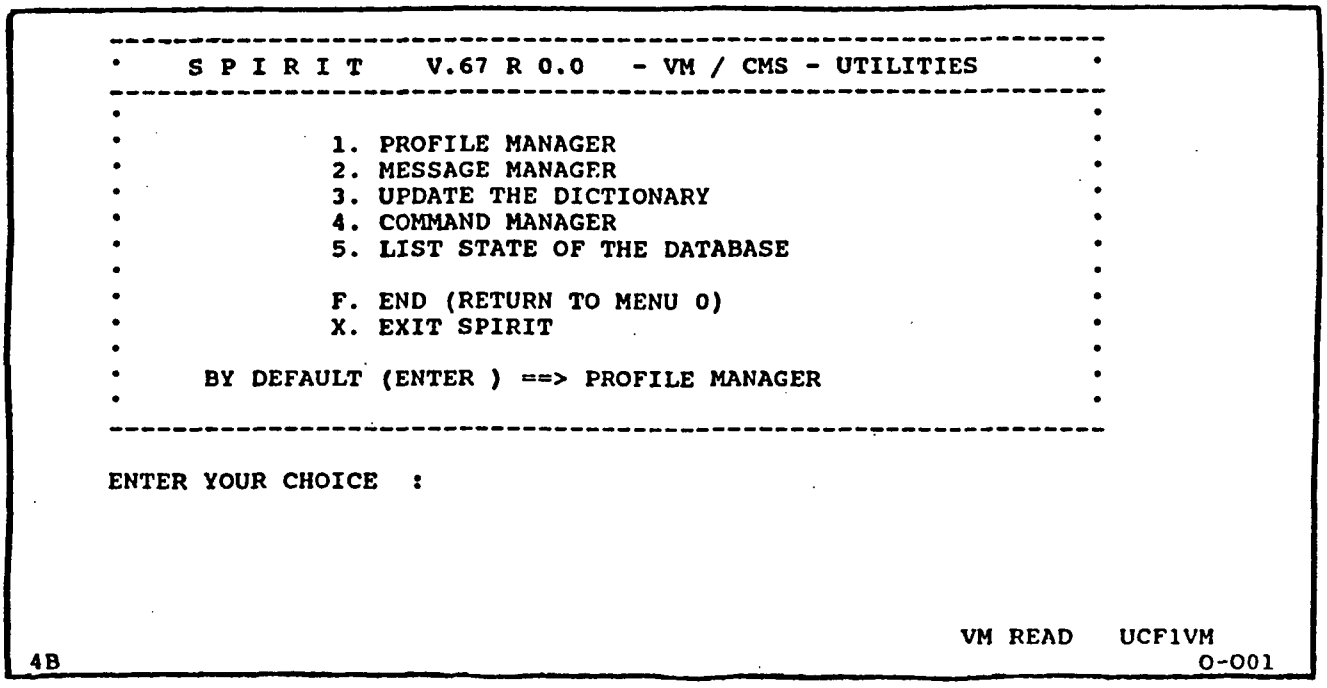

Figure #2 - SPIRIT's Utilities Menu

```
GENERATION DES DONNEES POUR LA DEFINITION DES CHAMPS SPIRIT

-------------------------------------------------------------------------------
    NOM DU CHAMP                NOM        TYPE DU    CHAMP      CHAMP      LG DE LA
                                COMPACT    CHAMP      VIDEO      IDENT      QUESTION
-------------------------------------------------------------------------------

 1. identifier_____________     id__       FACT         N          o          80_
 2. text___________________     txt_       text         N          N          80_
 3. _______________________     ____       FACT         N          N          ___
 4. _______________________     ____       FACT         N          N          ___
 5. _______________________     ____       FACT         N          N          ___
 6. _______________________     ____       FACT         N          N          ___
 7. _______________________     ____       FACT         N          N          ___
 8. _______________________     ____       FACT         N          N          ___
 9. _______________________     ____       FACT         N          N          ___
10. _______________________     ____       FACT         N          N          ___

-------------------------------------------------------------------------------

(TYPE DU CHAMP : 'TEXT' POUR TEXTUEL OU 'FACT' POUR FACTUEL OU 'DATE' POUR DATE
 CHAMP IDENT   : CHAMP D'IDENTIFICATION DU DOCUMENT)

VERIFIEZ ENCORE PUIS TAPEZ 'S' POUR SORTIR : s
4B                                                                      O-001
```

Figure #3 - Table for defining database fields in SPIRIT

```
********** FORMATTING SPIRIT RC=0
********** DOCS TO DELETE RC=0
STATE $SPIMAJQ FDOC G
+++ E(28) +++
********** BREAKING UP OF TEXT RC=0
WER226A END SYNCSORT, RECORD= 60, INCORE
********** SORT BEFORE ANALYSIS RC=0
********** MORPHOLOGICAL ANALYSIS RC=0
WER226A END SYNCSORT, RECORD= 68, INCORE
********** SORT BEFORE SYNTACTIC ANALYSIS RC=0
********** SYNTACTIC ANALYSIS RC=0
WER226A END SYNCSORT, RECORD= 44, INCORE
********** SORT BEFORE INDEXING RC=0
********** CREATING INDEX RC=0
WER226A END SYNCSORT, RECORD= 44, INCORE
********** SORT BEFORE WEIGHTS RC=0
********** CALCULATING WEIGHTS RC=0
WER226A END SYNCSORT, RECORD= 45, INCORE
********** SORT BEFORE MAIN BASE RC=0
********** CONSTRUCTION OF BASE RC=0
1 occurrence(s) changed on 1 line(s)
1 occurrence(s) changed on 1 line(s)

                                                        RUNNING    UCF1VM
4B                                                                  O-001
```

Figure #4 - Typical run-time messages created when indexing a database

```
    IL EST 17.16.07 - LE 18.08.89




--------------------------------------------------------------------------------
T,TULIB ->PROFIL DS LING      D,DPB ->PROFIL DS FIC BASE(GRILLE+DBDS+DCS)
CHOIX (TULIB,DPB,TERM,F OU ?) :

4B                                                                      O-001
```

Figure #5 - First screen seen after choosing the Profile Manager from the Utilities Menu

```
 **** PROFIL TYPE U : SPIRIT
 1. NRO DE L'UTILISATEUR  :  55
 2. DATE CREATION         :  860106
 3. DERNIERE MAJ          :  890817
 4. TYPE TERMINAL ASSOCIE :  2
 5. NRO IMPRIMANTE ASSOCIE:  2
 6. MESSAGES COMPLETS     :  0
 7. MODE D'AFFICHAGE (X)  :  FF
 8. TYPE LANGUE ASSOCIEE  :  1
 9. CONFIDENTIALITE BASE  :  0
10. CONFIDENTIALITE DOC.  :  0
11. NB BASES ACCESSIBLES  :  6
12. LISTE DES BASES       :




--------------------------------------------------------------------------------
NRO DE VARIABLE A MODIFIER : f

4B                                                                      O-001
```

Figure #6 - Screen typically seen when inside the Profile Manager to modify the list of available databases

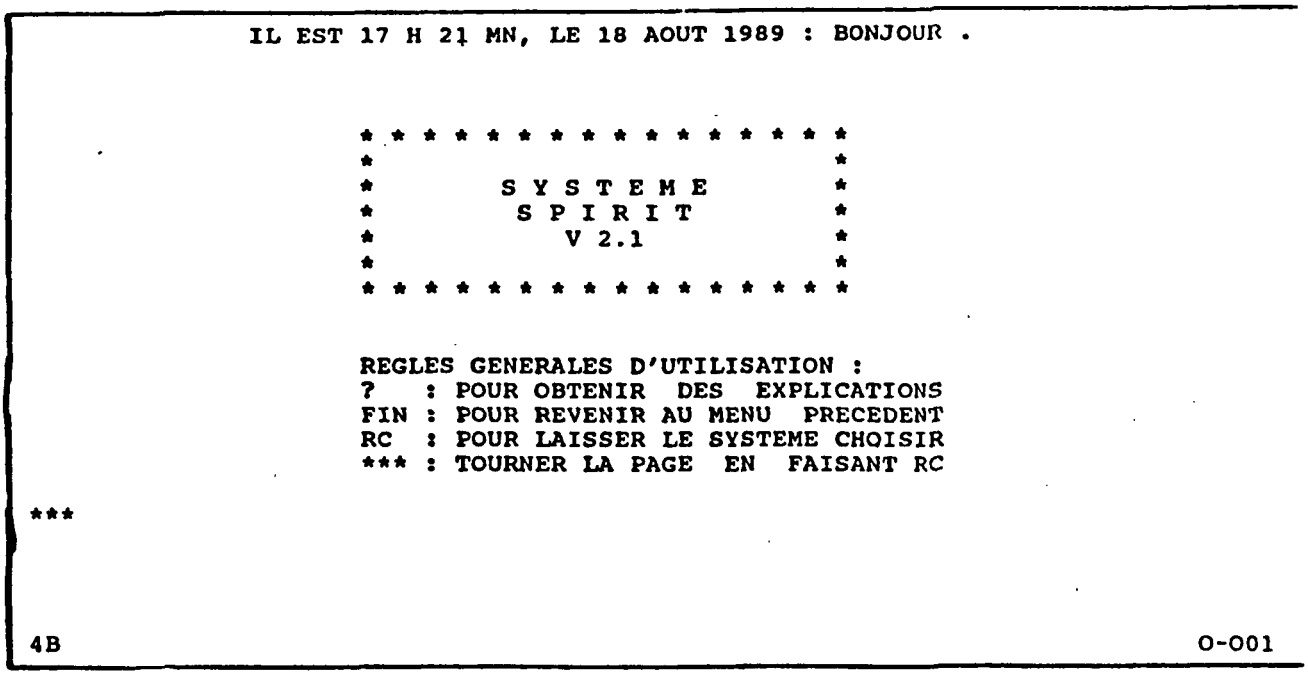

Figure #7 - Screen seen after choosing "Query the Database" from SPIRIT's Main Menu

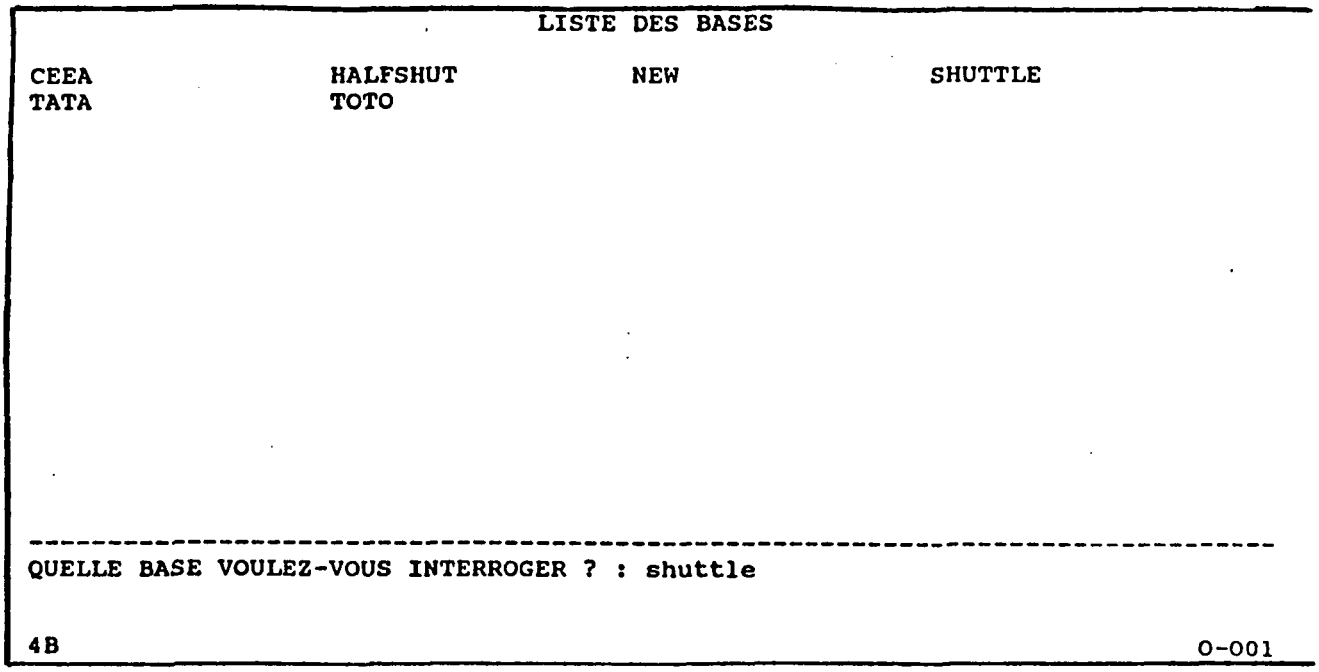

Figure #8 - Screen showing current databases available

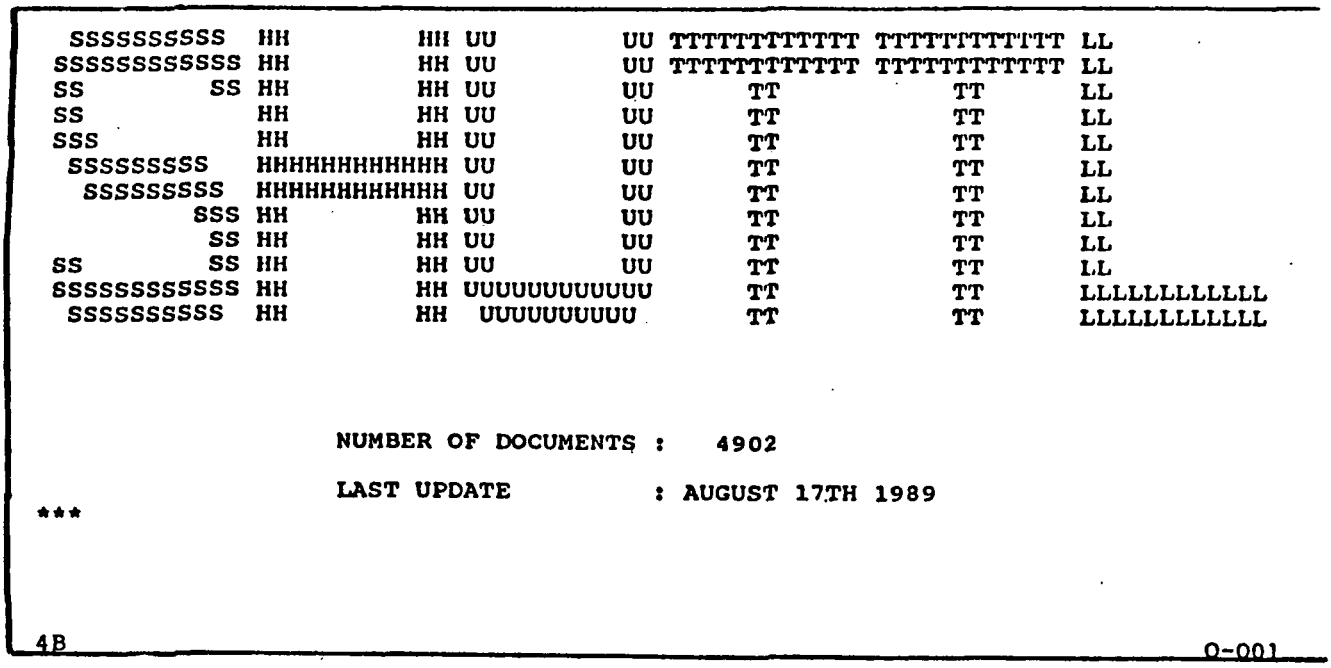

Figure #9 - Screen showing the number of documents in a database

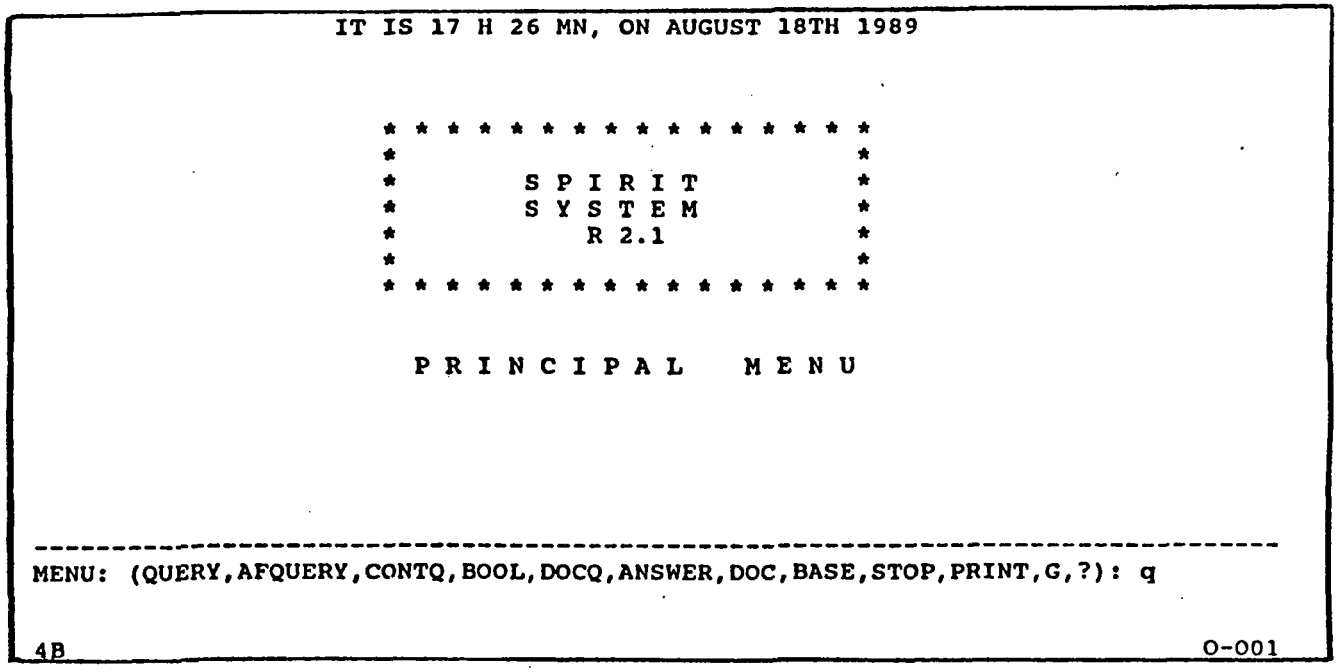

Figure #10 - Principal Menu in the database query area of SPIRIT

C-2

44

```
                    NATURAL LANGUAGE QUERY ON THE SHUTTLE BASE

<1> : where are the launch sites for the shuttle located?
EMPTY WORDS : where, are, the, for, the.
KEY WORDS   : launch, sites, shuttle, located.




***


4B                                                              O-001
```

Figure #11 - Typical response after a Natural Language Query has been entered into SPIRIT

```
CLASSES  NB DOCS  KEY-WORDS
    1         3   launch-sites,located.
    2        17   launch-sites,shuttle.
    3         2   launch,sites,located.
    4         2   sites,shuttle,located.
    5         9   launch,sites,shuttle.
    6        48   launch-sites.
    7         1   launch,shuttle,located.
    8         6   sites,located.
    9         5   launch,sites.
   10        18   sites,shuttle.
   11         4   launch,located.
   12         5   shuttle,located.
   13        54   sites.
   14        71   located.
BOTTOM OF LIST



--------------------------------------------------------------------------------
LIST OF CLASSES TO BE DISPLAYED (?) :

4B                                                              O-001
```

Figure #12 - Listing of possible relevant documents for the given query ranked in order of decreasing probabilities

```
TATA     FIIN     D1  F 80  Trunc=80 Size=19 Line=0 Col=1 Alt=2
===>

0000 * * * Top of File * * *
0001 $$1
0002 DOC001
0003 $$2
0004 This is a sample document after the markers for SPIRIT have been placed
0005 between the documents (in this case a document is a paragraph).  It is
0006 not required that a document be a paragraph.  Actually, it can be of any
0007 length, and can contain any number of paragraphs.
0008 $$1
0009 DOC002
0010 $$2
0011 The only requirement is that the fields in a document be separated by
0012 markers.  "$$1" on a line, followed by a document identifier is the first
0013 marker and field.  "$$2" on a line, followed by some text (a document) is
0014 the second marker and field.  One may use as many of these fields as
0015 needed.  For this example, only two fields per document are used.
0016 $$1
0017 DOC003
0018 $$2
0019 See the manual for further information.  This is the last document.
0020 * * * End of File * * *
```

Figure #13 - A small sample database showing the correct placement of document markers (three documents are present, each with two fields)

```
 Volume in drive B is NASAPROJECT
 Directory of  B:\

MANYDOCS C        3348   5-24-89   4:54p
QUICKFRE EXE      9744   6-14-89   1:40p
INKEY    TPU      4608   6-11-89   2:31p
WINDOWS  TPU     25136   6-05-89   6:14p
DEBUGA   TPU      1008   6-05-89   6:14p
STARTSCR TPU       960   6-05-89   6:14p
FILEVIEW PAS      2816   7-18-89   3:21p
MARK     PAS      6179   6-15-89   4:52p
CONSTANT TPU      1536   6-05-89   6:14p
CONVERT  EXE      9536   7-18-89   4:08p
MARK     EXE     21344   8-18-89   3:33p
LSORT    TPU      6608  12-31-87   4:00a
LSORT    PAS     16869  12-31-87   4:00a
SORT     TPU      5536  12-31-87   4:00a
SORT     PAS     16861  12-31-87   4:00a
STRINGS  TPU      2240   6-11-89   2:30p
CONVERT  PAS      6356   7-18-89   4:14p
SHUTTLE  LST       759   7-20-89   5:30p
TRUN     EXE     10846   6-06-89  10:33p
TURBO    TP       1206   7-06-89   4:41p
FREQCNT  C        2674   5-19-89   3:41p
TACCESS  TPU     22768   6-11-89   2:24p
TURBO    PCK      1201   8-18-89   3:41p
MERGETWO EXE     11956   6-06-89   1:38p
TRUN     OBJ      1044   6-06-89  10:32p
SCR      CFG      4000   6-09-89   2:26p
TRUN     C         733   6-06-89   4:03p
MAKEFREQ EXE     11522   6-06-89   4:20p
MERGETWO OBJ      2929   6-06-89   1:38p
MAKEALPH EXE     11540   6-05-89   4:33p
MAKEFREQ OBJ      1514   6-06-89   4:20p
MERGETWO C        2611   6-06-89   1:40p
MAKEALPH OBJ      2706   6-05-89   4:33p
FARHEAP  EXE      7488   5-31-89   8:51p
FREQCNT  EXE      9644   5-19-89   3:40p
MAKEALPH C        4425   6-05-89   4:32p
FILEVIEW EXE      6432   7-18-89   3:19p
QUICKFRE PAS      1414   6-14-89   1:40p
MAKEFREQ C        1302   6-06-89   4:19p
FREQCNT  OBJ      1925   5-19-89   3:40p
CONVERT2 EXE     10736   7-27-89   5:35p
CONVERT2 PAS      8462   7-27-89   5:35p
TEST     NDX      1461   8-18-89   3:37p
MANYDOCS OBJ      2451   8-18-89   3:45p
MANYDOCS EXE     10002   8-18-89   3:45p
```

Figure #14 - Directory of files on the NASAPROJECT disk created in the Fall of 1989 by Mark A. Clark

Figure #15a - Listing of the program CONVERT2.PAS written in Turbo Pascal

```
{This program takes a list of files and formats them for the SPIRIT database
system.  It puts in the special document markers between each paragraph, and
formats a line to a maximum of LINELEN characters.  One can specify if right
justification is wanted.  In the file that is a list of filenames, there should
only be one filename per line (drive and pathnames are allowed to preceed the
filename.  A filename preceeded by a # (like #a:myfile.doc) will be treated
as a single document by this program.  This is allowed for special parts of
the document created to override the automatic marking system.  If the # sign
is not present, each paragraph (if greater than 4 lines) will be treated as
a document in the output.  All files listed in the list of filenames will be
concatenated into one long file for SPIRIT to use.}

     { Created for NASA Public Affairs by Mark A. Clark.}

uses strings, crt;
type
bufftype=string[100];

var
inputfile, inputlist, outputfile: text;
readstr : string[50];
buff : bufftype;
testchar, testrightjust, inchar, holdchar: char;
oddchar, i, j: integer;

const
linelen: integer=76;   {MAXIMUM LINELEN IS 80}
linecnt: integer=0; buffcnt: integer=0;
lastblank: integer=0;
doccnt: longint=1;
holding: boolean=false;
specialfile: boolean=false;
label redolist, redooutfile, restart;

{procedure strips out any trash bits in ascii text by wordprocessors}
procedure wordprocscreen(var ch: char);
var
bh: byte;
begin
bh:=ord(ch); oddchar:=0;
bh:=bh and $7f;
if ((bh in [10,13,26]) or ((bh>31) and (bh<127)))
   then ch:=chr(bh)
   else
      begin
      ch:=' '; oddchar:=1;
      end;
end;

procedure makelist(myfilestr: string);
var
filestr: string[50]; outputlist: text;
begin
writeln('Limit filenames to 50 characters, please.  Hit RETURN to end list.');
assign(outputlist, myfilestr);
{$I-}
reset(outputlist);
{$I+}
if ioresult=0 then
   begin
```

Figure #15b - Continuation of the listing for CONVERT2.PAS

```
   close(outputlist); erase(outputlist);
   end;
rewrite(outputlist);
write('Enter a filename: '); readln(filestr);
while filestr<>'' do
begin
   writeln(outputlist, filestr);
   write('Enter another filename: '); readln(filestr);
end;
writeln('Finished making file list.....');
close(outputlist);
end;

procedure rightjust(line: bufftype; len:integer);
var
blanks, shifts: array[1..25] of integer;
numblanks, curblank, pad, rtshift: integer;
newline: string[80];
tempstr: bufftype;
begin
numblanks:=0;
tempstr:=line;
for i:=1 to 25 do shifts[i]:=0;
for i:=1 to linelen do newline[i]:=' ';
for i:=2 to len-1 do
   if (tempstr[i]=' ') and (tempstr[i-1]<>' ') and (tempstr[i+1]<>' ') then
      begin
      inc(numblanks); blanks[numblanks]:=i;
      end;
pad:=linelen-len;
while pad>0 do
   begin
   if pad<=numblanks then
      begin
      for i:=1 to pad do
         inc(shifts[i]);
      pad:=0;
      end
   else
      begin
      for i:=1 to numblanks do
         inc(shifts[i]);
      pad:=pad-numblanks;
      end;
   end;
rtshift:=0; curblank:=1;
for i:=1 to len do
   begin
   newline[i+rtshift]:=tempstr[i];
   if i=blanks[curblank] then
      begin
      rtshift:=rtshift+shifts[curblank]; inc(curblank);
      end;
   end;
newline[0]:=chr(linelen);
writeln(outputfile, newline); writeln(newline);
end;


{MAIN PROGRAM}
```

Figure #15c - Continuation of the listing for CONVERT2.PAS

```
begin
clrscr;
writeln('Program takes a file created by ascii wordprocessors and formats the');
writeln('text for use in the indexing system of the SPIRIT database.  Each');
writeln('line is formatted to a specific line length and ends with CR.  Garbage');
writeln('control characters are removed from the file.  Segmentation of the');
writeln('file into separate documents is based on finding a carriage return,');
writeln('hence the end of a paragraph.'); writeln;
redolist:
writeln('Enter the name of the input file (list of files) to convert.');
readln(readstr);
write('Do you want to create the list of input files now? (Y/N)');
testchar:=readkey; writeln;
if upcase(testchar)='Y' then makelist(readstr);
assign(inputlist, readstr);
{$I-}
reset(inputlist);
{$I+}
if (upcase(testchar)<>'Y') and (ioresult<>0) then
   begin
   writeln; writeln('*** the list of input files does not exist ***');
   writeln('*** please re-enter the input file (list of files) again ***');
   writeln; goto redolist;
   end;
write('Do you want the output right justified? (slower to process) (Y/N)');
testrightjust:=readkey; writeln;

redooutfile: writeln;
writeln('Enter the name of the file CONVERT produces for the SPIRIT system.');
readln(readstr);
assign(outputfile, readstr);
{$I-}
reset(outputfile);
{$I+}
if ioresult=0 then
   begin
   writeln; writeln('*** This output file already exists ***');
   write('Do you want to over write it? (Y/N).');
   testchar:=readkey; writeln;
   if upcase(testchar)<>'Y' then goto redooutfile;
   end;
rewrite(outputfile);

writeln;
writeln('=============================================================');
writeln('*** TEXT PROCESSING BEGINNING ***');
writeln('=============================================================');

repeat
   readln(inputlist, readstr);
   (test to see if filename begins with # to indicate specialfile)
   if readstr[1]='#' then
      begin
      specialfile:=true;
      move(readstr[2], readstr[1], length(readstr)-1 );
      readstr[length(readstr)]:=' ';
      readstr[0]:=chr(length(readstr)-1);
      end;
   assign(inputfile, readstr);
   {$I-}
```

Figure #15d - Continuation of the listing for CONVERT2.PAS

```
reset(inputfile);
{$I+}
if ioresult<>0 then
   begin
   writeln; writeln('*** file ',readstr,' does not exist ***');
   writeln('*** you must restart the program ***');
   close(inputlist); close(outputfile); exit;
   end;
holding:=false;
writeln(outputfile, '$$1'); writeln('$$1');
writeln(outputfile, 'doc', doccnt:6); writeln('doc', doccnt:6);
writeln(outputfile, '$$2'); writeln('$$2');
inc(doccnt); linecnt:=0;
repeat
begin
   restart:
   if holding then
      begin
      holding:=false; inchar:=holdchar;
      end
   else
      read(inputfile, inchar);
   if ord(inchar)=9 (A TAB) then
      begin
      repeat
         inc(buffcnt); buff[buffcnt]:=' ';
      until (buffcnt mod 8=0);
      goto restart;
      end;

   wordprocscreen(inchar);
   if oddchar=1 then goto restart;
   inc(buffcnt);
   if inchar=' ' then lastblank:=buffcnt;
   if (not (ord(inchar) in [10, 13, 26])) then
      if buffcnt<=linelen then
         buff[buffcnt]:=inchar
      else
         begin
         buff[buffcnt]:=inchar;
         buff[0]:=chr(lastblank-1);
         if upcase(testrightjust)='Y' then
            rightjust(buff, lastblank-1)
         else
            begin
            writeln(outputfile, buff); writeln(buff);
            end;
         inc(linecnt);
         for i:=1 to buffcnt-lastblank do
            buff[i]:=buff[lastblank+i];
         buffcnt:=buffcnt-lastblank;
         lastblank:=0
         end
   else (then we have a carriage return(10), line feed(13), or EOF(26).)
      begin
      buff[0]:=chr(buffcnt-1);
      writeln(outputfile, buff); writeln(buff);
      buffcnt:=0; lastblank:=0;
      inc(linecnt);
      read(inputfile, holdchar);
```

Figure #15e - Continuation of the listing for CONVERT2.PAS

```
          while (ord(holdchar) in [10,13]) do
             begin
             inchar:=holdchar; read(inputfile, holdchar);
             writeln(outputfile); writeln;
             end;
          holding:=true;
          {
writeln('inchar= ',ord(inchar),' linecnt= ',linecnt);
writeln(outputfile,'***inchar*',ord(inchar),'*linecnt*',linecnt);
          }
          if not specialfile then
             if ((not (inchar=#26)) and (linecnt>2) and (holdchar<>#26)) then
                {don't want paragraphs with less than 6 lines}
                begin
                writeln(outputfile, '$$1'); writeln('$$1');
                writeln(outputfile, 'doc', doccnt:6); writeln('doc', doccnt:6);
                writeln(outputfile, '$$2'); writeln('$$2');
                linecnt:=0; inc(doccnt);
                end;
          end;


   end; until (inchar=#26);
   close(inputfile);
   if specialfile=true then specialfile:=false;
until eof(inputlist);
close(inputlist); close(outputfile);
writeln('Program finished.....SPIRIT text file created.');
end.
```

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A PROTOTYPE TEXT RETRIEVAL SYSTEM FOR ANSWERING NASA KENNEDY SPACE CENTER MEDIA QUESTIONS

A research project report submitted to the

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ABSTRACT

The Public Affairs Office of NASA at the John F. Kennedy Space Center is inundated with hundreds of media questions each year. Public Affairs personnel currently answer questions by manuallly searching volumes of information to find an answer. This report reviews some software systems that automate the document searching process. The report focuses on a particular text retrieval system called SPIRIT (Syntactic and Probabilistic Indexation and Retrieval of Information in Texts). An evaluation of SPIRIT's performance in retrieving text is presented using NASA Public Affairs documents within two prototype databases. In addition, software and hardware recommendations are included here about an appropriate NASA environment for running SPIRIT or a SPIRIT-like system. Finally, a SPIRIT user manual appears here describing how to set up databases in SPIRIT, and how to use its text retrieval features. Recommendations made to NASA could result in faster and better responses to media questions as well as save taxpayers' dollars.

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A. Questions and Retrieval Times
B. Instruction Manual for Creating Databases with the SPIRIT System

1. GENERAL BACKGROUND INFORMATION

The amount of textual information is increasing at an overwhelming rate. Dataquest estimates that the amount of information produced will double every three years by the year 2000 [CISL88b]. One is overcome by the number and size of documents one large organization such as NASA makes use of each year. An example from NASA which is important to the public is the "NASA National Space Transportation System Reference", Volumes I and II (hereafter referred to as the shuttle manual), by the Rockwell Corporation [NASA89]. This manual is over 1000 pages long and NASA Public Affairs personnel at KSC use it as a reference to answer media questions.

The intent of this section is to provide background information concerning the technology available for automated text search and retrieval systems. Later sections of this report will focus on a commercial text retrieval system called SPIRIT (Syntactic and Probabilistic Indexation and Retrieval of Information in Texts), and the text retrieval problems of NASA KSC Public Affairs personnel.

1.1 BOOLEAN AND CONCORDANCE BASED SEARCHING

Boolean searching techniques [RIJS79] involve finding one or more words in a text with the logical operators OR-AND-NOT. They are a common method of information retrieval. However, they often lead to incomplete or irrelevant retrieval of full text documents. A user may retrieve and examine many texts that are relatively useless with regard to a given question.

Another method used for text retrieval involves searching based on a single keyword, such as in a concordance [THOM81]. A concordance contains an alphabetic index of the principal words of a book with a reference to the passage in which each occurs. As an example, a product for the IBM PC called WordSearch, keeps a dictionary of all the distinct words in both the Old and New Testaments of the Bible, minus a select group of the 50 most common words (which hold no information). WordSearch then keeps a table that contains a list of every occurrence of every word in its dictionary for the whole document (Bible). For each keyword, it produces a list of every reference that contains the keyword. Reference lists may be intersected or unioned with one another to simulate a Boolean type search. Verses can be displayed in various modes such as highlighted with keywords given a distinct color.

The major disadvantage in a concordance or Boolean search based system is the inability to propose queries in a natural language without major modifications. A question would have to be broken into useful keywords and useless words. Then perhaps some priority should be given to some of the keywords. Some

keywords may be more significant than others, something which a novice user may not realize.

1.2 HYPERTEXT

Hypertext systems offer the ability to build (with an editor) documents or text which are linked to other related documents. Hypertext systems try to mimic the brain's ability to store and retrieve information in a quick, intuitive manner. Only recently have hypertext software packages appeared for microcomputers [RAY 89].

Hypertext is a document collection in which information (text, graphics, etc.) is stored in nodes connected by links. Each node is analogous to an index card with some text on it, or a picture with a caption. Many of these index cards could form a file, and all the files could fill a file cabinet in the analogy. Mainly, these nodes fall into two classes. One class of nodes has information which fits onto one screen (see Apple's Hypercard in the software reviews). Another class of nodes includes more than one screen of information (see Guide in the software reviews). Links join related sections (nodes) to one another to form the file [SMIT88]. The linkage paths are manually, rather than automatically, placed within the text of the document.

Hand linking the network of nodes is a time consuming task which requires much thought. The value of the network is in the quality of information in each node, as well as the proper placement of links between nodes. With volumes of information waiting to be placed in these databases, there is not enough time or hypertext technicians to hand-link them into high quality hypertext documents [RAY 89]. Even when a hypertext document has been well designed, it is possible to get lost following links when browsing through unfamiliar information. A good overview of hypertext systems and concepts can be found in [SMIT88], [AKSC88], [RAYM88], and [CONK87].

It would be unreasonable to expect NASA Public Affairs personnel to edit every page of text within their large document collection to determine possible linkage paths to other pages of text. Consequently, hypertext systems, per se, are not appropriate to automating how NASA Public Affairs personnel obtain answers to media questions.

1.3 NATURAL LANGUAGE PROCESSING

Typically, in natural language processing, syntactic parsing of English sentences is involved. This must be performed before further processing, such as understanding meaning, can be attempted [DRIS89]. There is no known syntactic parsing algorithm for all of English. In fact, it is usually very easy

to find English sentences which cannot be parsed by so-called 'parsing' systems. Typically, the excuse given when such sentences are pointed out, is that the parser just needs adjusting or extending. This is usually a nontrivial task, and the adjustments or extensions never cease. Consequently, systems which claim natural language query capability must be examined closely to see what is meant by the claim.

SPIRIT claims full natural language query capability. Examination of the system's operation reveals that syntactic parsing is really not involved. Instead linguistic and probabilistic processing is involved. These are information retrieval techniques which have been shown to be effective in regard to text retrieval.

Natural language processing represents the Artificial Intelligence (AI) point of view for information retrieval. People in AI often use a rule based system to understand natural language. Many of their techniques are borrowed from compiler theory and other related fields. It has been difficult to describe the English language with a finite grammar through a finite set of rules. Large portions of the entire English language have been modeled, but no one has yet found all the rules necessary to describe all of English. START, reviewed in Section 3, uses a rule base and AI techniques to analyze text.

1.4 PROBABILISTIC AND LINGUISTIC PROCESSING

Early research in information retrieval began in the late 50's to early 60's. Information retrieval is concerned with retrieving documents pertinent to a given query. In principle, this is simple. Given a store of documents and a question to answer, one could read all the documents in the store. Then, one could retain all the documents that are revelant, discarding all others. When high speed computers became available for non-numerical work, many thought that a computer would be able to 'read' an entire document collection to extract the relevant documents. This turned out to be completely impractical. Using the natural language text of the documents not only causes input and storage problems, but also the unsolved problem of characterizing the document's content. What is desired is a text retrieval system that, with minimum human intervention, will generate from the input text a document representation that is adequate for automating the retrieval process.

The purpose of any automatic retrieval strategy is to retrieve all the pertinent documents at the same time retrieving as few of the non-relevant documents as possible. A human can establish the relevance of a document with his intellect. For a computer to do this, it needs a model within which relevance decisions can be quantified. Most of the research in information retrieval is concerned with different aspects of such a model.

Two primary approaches have been used: statistical (probabilistic) and linguistic.

Probabilistic methods theorize that word significance is related to word frequency. Luhn [RIJS79] pioneered research in this area using the frequency of words in the document to determine a list of keywords or terms to represent or characterize the document. Keywords are often the outcome of some process such as, for example, the gathering of different morphological variants of the same word. The frequency of occurrence of each keyword in the text was also used to indicate its degree of significance. His method gave a weighted keyword description of the document. The early ideas of Luhn are still being developed. Many automatic methods of characterizing documents are based on his early work [RIJS79].

Maron, Kuhns, and Stiles used the statistical distribution of words to aid retrieval [RIJS79]. They also used statistical associations between keywords to construct a thesaurus that aids retrieval.

Most statistical methods of text retrieval make use of an inverted index file of keywords from the document. Two words that are morphologically similar are assigned to the same stem keyword. An inverted file is a list of all the tokens found in the text beside which are the locations of each occurrence of the token. Others methods make use of clustered files, or some other organizational technique that represents the content of a document.

Probabilistic models have been applied to the distribution of words in a document with some success. One model [RIJS79] describes 'specialty words', which are content bearing, and 'function words', which are not. Function words were found to closely model a Poisson distribution over all the documents, whereas specialty words did not. This difference can be used to decide whether a word is important enough to be kept in an index of the documents. A word randomly distributed according to a Poisson distribution is assumed not to be informative of the document in which it occurs. Whereas, a word not following a Poisson distribution is assumed to convey information as to what the document contains. This model has not yet been tested with regard to retrieval effectiveness.

Other probabilistic models deal with finding parameters of a matching or retrieving function by sampling subsets of the documents [RIJS79]. This matching function is a mathematical tool used to decide which documents might be revelant. The mathematics of these models are fairly sophisticated, although many of the equations used in them follow from Bayes' Theorem.

Regardless of the model chosen, the result is that the text retrieval system will respond to each query with a ranking of the

documents (in the collection of all documents) in order of decreasing probability of relevance to the query. Probabilities are estimated as accurately as possible on the basis of whatever data are available to the system for this purpose.

Linguistic techniques are less available due to the lack of formal supporting theory. Users of linguistic methods for information retrieval are more concerned with the grammatical details of the text, such as verb classification and how words behave, than AI people are. Linguistic methods are based on semantic analyses of the document. This approach performs a full syntactic analysis (parse) to join the individual words of a sentence. Sentences are joined into phrases, phrases into clauses, and so on. A full analysis requires extensive semantic knowledge, usually in the form of a rule base or dictionary. Systems with a high degree of sophistication remain experimental in nature. Most of these systems are limited in their generality and must be fine tuned for a new application, which is a major headache. Besides being complex, they are computationally expensive.

Systems that use a linguistic approach commonly respond to a query in the same manner that a probabilistic system would. They return a ranked list of pertinent documents.

1.5 INFORMATION GATHERED FROM NASA PUBLIC AFFAIRS

NASA KSC Public Affairs personnel read and obtain information from enormous volumes of printed documentation to answer media questions. Up to now the process of answering media questions has been manual, and hence cumbersome and slow. An increase in questions is expected. Experience plays a key role in how quickly a particular employee might be able to answer a question. Newly hired personnel require long training periods to learn how to answer media questions.

Answers to media questions are saved for later reference, and are later searched to see if a question being asked has already been answered. Also, this is done to avoid giving different answers to the same question, and to reduce duplication of effort. Current sources of documents are mostly in paper form, however some are electronically stored. More are expected to be stored electronically in the future.

Press releases at KSC are currently created using Wordstar 2000. Other documents may come from other sites via electronic mail. These documents are downloaded from other NASA offices across the country to KSC, and then formatted with Wordstar 2000 at KSC, usually on a Compac 386 microcomputer.

Other documents that NASA uses come from outside contractors, such as Rockwell, which produces the "NASA National

Space Transportation System Reference", Volumes I and II [NASA89] (more commonly called the shuttle manual). These documents are about 1000 pages long (2.6 megabytes). They come in two versions (IBM-PC and Apple MacIntosh), and were created using WordPerfect.

Several question and answer sheets were obtained from the press site. These sheets fill several notebooks that occupy a bookcase. They go back to about 1978-79, and most questions are on a standard single sheet query form. The current question and answer process is unorganized and if a question is asked again the notebooks will not be consulted unless the person can remember where the question might have been placed in an old notebook. If the media person who asked the question is not in a big hurry, then a NASA employee might go through the notebooks more carefully to see if the answer is already there. During a launch, there are about a dozen NASA employees at the desk answering media questions. Many answers are given from memory. Mr. Dick Young, press site manager, said an ideal system would be where a media person could go to a computer terminal, and enter a question. This would free up KSC press staff to do other tasks, such as answering questions for which answers cannot be found in a computer system. As Mr. Young stated, "We have a great information collection system, but a terrible information retrieval system."

After talking to Mr. Hugh Harris, director of NASA KSC Public Affairs, it was discovered that perhaps their largest document is the shuttle manual, which is just over 1000 pages (2.6 megabytes). Estimates were also made about how many pages of documents could be expected to be added to the text database annually. It was estimated that approximately 18 megabytes (4000 to 5000 pages) would be added to the text retrieval system annually when fully implemented. Many documents would expire and need to be removed or replaced periodically. After the text retrieval system is fully operational, it is estimated that approximately 960 megabytes of text would be stored, or roughly 260,000 pages. This was an estimate based on how many bookcases would hold all the documents needed, a standard page size and thickness, as well as an average number of bytes per page. These estimates were made to help decide future storage requirements.

2. REVIEW OF TEXT RETRIEVAL SOFTWARE

The term hypertext was first coined by Ted Nelson, a researcher of text retrieval systems, in 1965 [FRAN88]. Several events have led to the current feasibility of hypertext systems. In the mid 1960's, Doug Engelbart managed to develop critical features, including bit mapped displays, the mouse, icons, and the pull down menu. Hypertext reguires a bit mapped monitor to manipulate text and graphics simultaneously. While others

developed the technological basis, Ted Nelson refined and popularized nonsequential writing, or hypertext as he called it.

Most of the information for the reviews below comes from articles gathered about these systems through an extensive literature search. The only systems personally obtained and used by this author besides SPIRIT, were Dialog and ZyIndex. Two systems, START and SPIRIT, will be reviewed in Section 3, since it is felt that a combination of these two systems will solve the information retrieval problems of NASA Public Affairs.

2.1 BELLCORE ADVISOR

Bellcore Advisor [CISL88a] was created by Bell Communications Research to provide support for the seven regional Bell companies formed after the breakup of AT&T. It is a system that allows the user to input a keyword to find parties within Bellcore who can answer a specific question. It has the ability to recognize plain English queries, to relate them to 7100 technical terms, and to assign a relevance index form -1 to +1 to each hit or citation. Any index over .5 indicates there is a good chance of finding what was requested. Bellcore Advisor runs on a Sun workstation, but [CISL88a] did not mention whether it runs on other computers.

2.2 DIALOG

Dialog Information Services [ORWI89] is based in Palo Alto, California. It is a subscription service that has hundreds of databases stored in a large mainframe. A user can access Dialog by a PC and a modem over phone lines. There is a yearly fee ($35), along with online time and record printing charges. These charges completely depend on which databases the user is accessing. For example, printing (output to screen) may vary from a few cents to over a dollar per record. The user is charged for any output to the screen from any of the databases.

Often a company will give Dialog a database to index and let other subscribers use it. There is normally no charge for this as money is made by others accessing the databases. It is usually not the case that the organization that provides the database also wants to access it, such as NASA Public Affairs.

Dialog makes use of inverted indices to search for patterns of keywords based on a Boolean like query language. Some learning or training time is involved in learning the language. After a few hours, a user can know enough of the query language to begin using Dialog. Dialog offers seminars to learn more advanced searching strategies. The query language offers standard Boolean features such as AND, OR, NOT, proximity searching, and wildcards, as well as other special search

features. Each query produces a set of documents, with an associated number of hits. The number of hits can be reduced by making the query more specific. Retrieval times are reasonable (few seconds), and depend on the time of day and the complexity of the query. Some manual searching through their catalog must be done before calling Dialog to find out which databases one wants to search through. Dialog also sells a few databases on CD-ROM.

2.3 FOLIO VIEWS

Folio Views [ALLE89] combines several features for DOS machines: text retrieval, hypertext linking, word processing, directory management, and electronic publishing. Folio Views indexes every word of a text file and compresses both the text and index into as little as half the space of the original ASCII file. Each logical piece of information is called a folio. Typically, this consists of a paragraph. Markers show where each folio begins, and the user can jump from one marker to the next with a single keystroke. A user can also jump to the next page (screen) or go directly to any folio specified.

Its major drawback is its slow scrolling when updating a screen. However, Folio Views' strength in text searches offset the scrolling problem, and one can do searches from any view. Because of its unique index, most searches are instantaneous, even on databases many megabytes in size. Searches can be based on a single word, or on full logical expressions using Boolean logic, nesting, wild cards, and proximity matching. The user can create links between views to create hypertext like jumps. Because of the way Folio Views organizes its index, any user can easily add, delete, or edit a database without reindexing the entire database. Folio markers have to be manually placed in the text. Among its major advantages are its indexing and compression techniques.

2.4 GUIDE

Guide [FRAN88], by Owl International, was one of the first hypertext products, now available for the MacIntosh and MS-DOS based machines. The documents produced by Guide are called guidelines, and are equivalent to a 'field-less' record. The underlying concept of Guide is that of 'buttons', which are sections of text or graphics that are connected to some other text or graphics. A button could be a word, sentence, or picture.

Guide uses three different types of links to these buttons. Replacement links cause the text or graphics in the current window to be completely replaced by the text or graphics pointed to by the link. Note links display the destination text in a

pop-up window. Reference links bring up a new window with a cross reference to other pertinent information in the same guideline or a different one. Text, graphics, whole guidelines, and even other buttons may be stored underneath the original user defined button. Buttons may be nested to any desired level.

Creating a guideline is just like entering text into a word processor. When the creation of a button is desired, the user selects the text for that button with the mouse, as would be done to select text to be copied or cut. Then the user selects what type of button to create from the pull-down menus. While Guide allows regular text files to be imported, there are two problems.

First, Guide cannot accept text files longer than 40,960 bytes without taking the part of the file longer than 32,780 bytes and storing it under a button. To prevent this arbitrary action, the user must split the file so no single part is longer than 40,960 bytes. Secondly, extended ASCII characters are converted improperly. Perhaps a more difficult problem lies with using large guidelines. There is the inability to modify a Guide structure once it is created. A structure is simply the chain of links among buttons. Guide permits modification of button labels and content within a structure, but not the type of link. If the link is deleted , the entire content of the structure below this point is destroyed. As of February 1988, Guide's retail costs are $135 for the MacIntosh, and $200 for DOS PCs.

2.5 HYPERCARD

Hypercard [BRYA87] is a Rolladex-like system with hypertext linking. It is made for the Apple MacIntosh computers with at least one megabyte of RAM (it is now included with new MacIntosh computers). The 'cards' are limited to a screen, and can be made of any combination of text, graphs, digitized photos, graphics, and even sound. Conceptually, the cards are stored in stacks, where the user has put in some links between related cards. There may be an unlimited number of links between cards. It uses menus and icons combined with a nice user interface for easy selection of cards and options. Hypercard also has its own command language for those with more computer expertise; it is called Hypertalk.

2.6 INTERMEDIA

Intermedia [SMIT88] is a large scale hypertext/hypermedia system developed at Brown University in 1985. It runs on IBM RT PCs running Unix 4.2. The IBM RT (resource sharing, time sharing) was developed four to five years ago, and is a multi-user, low end minicomputer that has its own proprietary operating system. RTs are being phased out in preference of networked systems. Intermedia has a desktop environment similar

to that found on the MacIntosh. Its applications include word processing, a graphics editor, and a time line editor. It has a feature to project a three dimensional wireframe viewer on the screen for navigating through the various documents. With these applications, users enter data and then link significant pieces of information together (the user must enter the links). Global maps showing all the links available in the system aid in navigation, but sometimes become complex and confusing. It is a multiuser system, meaning that users can make links while other users are browsing the existing linked information.

2.7 KMS

KMS (Knowledge Management System) [AKSC88] is a distributed hypermedia system for workstations based on research done at Carnegie Mellon University. Its applications include electronic publishing, on-line manuals, electronic mail, on-line help for other software, project management, and others. A KMS database consists of interlinked, screen sized WYSIWYG workspaces called frames which contain text, graphics, and image items. Individual items can be linked to other frames or used to invoke programs. The database can be distributed over an indefinite number of file servers and can be as large as available disk space permits. Most KMS databases have a strong hierarchical orientation, although they may have any structure that their creators desire. The KMS user interface employs a form of direct manipulation designed to exploit a three button mouse. Users navigate from frame to frame by pointing the mouse cursor at an item linked to another frame and clicking the left mouse button. Running on Sun and Apollo workstations, KMS accesses and displays frames in less than half a second, on average. It does not have two distinct modes for navigation and editing. A user can edit the content of a frame at any time. KMS was developed to exploit what the developers believed would be the dominant architecture for organizational computing environments in the 1990's. That is wide area networks of large screen, disk-less workstations.

2.8 NOTECARDS

Notecards [HALA88] is primarily an authoring system designed to provide its users with facilities for creating and modifying hypertext structures. It is a workstation based system designed to help people work with and organize ideas. Its intended users are authors, researchers, designers, and other intellectual users engaged in analyzing information. Notecards is basically a network of electronic notecards interconnected by typed links. The system includes facilities for displaying, modifying, manipulating, and navigating through this network. It was implemented within the Xerox Lisp programming environment and has two primary constructs, notecards and links.

A notecard is a piece of text, structured drawing, or a bitmap image with a title. There are various types of notecards based on their content (text or image), and every notecard can be edited. Links are used to interconnect individual notecards into networks or structures of related cards. The user must supply the source card and destination card for the link. There is also a browser card which is a notecard that contains a structural diagram of a network of notecards. These diagrams are computed for the user by the system based on the current links. Categories of similar cards are organized into fileboxes.

Navigation, whereby the user moves through the network by following links from card to card, is the primary means for accessing information in Notecards. There is a limited search facility that can locate all cards matching a particular user specified string. This query based access is very slow and limited to simple strings or keyword matching. There is no natural language query interface.

2.9 ORIGIN

Origin [REAL89], created by Realstream Ltd., is a system from Dorchester, England. It is an archiving and fast information retrieval system using optical data disks. Origin claims it can quickly retrieve two billion documents of any length, and can handle both image and text. Every word is indexed as it is input. It uses optical WORM (write once read many) technology. Origin claims it can 'bolt on' to any major mainframe. One optical platter can hold as much information as five four-drawer filing cabinets. Upon entry, the data is parsed into the database and indexed automatically. When information is required from the Origin, the user can issue search requests in a natural language. The software locates any document by occurrence of words, related words, or even phrases. It also allows display, print, or processing facilities to be accessed.

2.10 RUBRIC

RUBRIC [TONG87] is an expert system which searches for word patterns in online text, rather than retrieving preindexed documents. Instead of trying to parse the text, it searches for textual evidence (in the form of word patterns) that indicates that a concept is being discussed. The semantic structure of the document must be encoded in RUBRIC. This is done by the user creating rules in a LISP like language. There are modules to provide means to create rules, edit rules, browse existing rule bases, and perform some sensitivity analysis. This however, is a very difficult task. Like most expert systems, RUBRIC requires users to tailor the system's rule base to the domain of application. While this allows specialized rule bases for each user's area of interest, it requires a lot of work to adapt the

system to a new subject area. The current version is implemented in Common Lisp and C on a Sun Microsystems Workstation, and makes use of an ADS proprietary object oriented programming environment.

2.11 SCISOR

SCISOR (System for Conceptual Information Summarization, Organization and Retrieval) [RAU 88] is a prototype intelligent information retrieval system currently under development at GE's Research and Development Center. It is an AI system that partially parses short texts in constrained domains to aid understanding. SCISOR is designed to read short articles from an on-line source of information and extract information from those articles.

Currently, the SCISOR system builds an internal knowledge base from documents in the domain of corporate mergers and takeovers. From this it answers natural language queries with natural language answers. Input stories and questions are represented in the KODIAK knowledge representation language. The system is domain dependent and requires that domain dependent scripts be encoded by hand for each application area. Hence, it would not be revelant to meeting KSC Public Affairs Offices' needs. In addition, the slow and error-prone process of building a knowledge base from natural language text makes this approach unsuitable for large, dynamic collections of documents.

SCISOR has three main components. These components are the text processing mechanism, the two pass retrieval mechanism, and the summarization mechanism. The text processing mechanism includes a top down conceptual analysis (full parsing) and a bottom up linguistic analysis (partial parsing). Using two parsers improves the depth and accuracy of the understanding process. According to [RAU 88], SCISOR's method of retrieval allows for close matching between the items of interest and the items actually present in the source documents. Text summaries are produced by generating in natural language the contents of a particular category, such as corporate takeovers. This feature is not fully operational, since the natural language generator of SCISOR has not yet been connected to the system.

SCISOR is implemented in Common Lisp, and has a lexicon of over 5,000 words. The text processing mechanism is still being refined. There are additional experiments being performed with other domains. SCISOR will probably remain experimental for some time to come.

2.12 VERITY

Verity [CISL88b] offers TOPIC, which is a concept based retrieval system, as opposed to a word oriented Boolean query language. Retrieval is not based on a linear string of words, but an outline (topic tree) that describes a topic. The topic trees look like genealogical charts. Weights may be assigned as revelance factors. The weighting factors give the retrieval software the information to construct a relevance score for each article. Using this index, the articles are presented in descending order of relevance. The user can read until the rate of return is not worth continuing. As a side note, Verity also includes Boolean searching techniques as well as a keyword searching tool.

Verity is very speed conscious. A few articles are displayed for the user while the program continues to search through the database for others. Verity sees a market in intelligence gatherers in the federal government, law enforcement agencies, media groups, special libraries, and consulting firms. At present, the software works in a networked environment on Digital Equipment's VMS operating system, MS-DOS, and Unix (Sun Microsystems).

On a multiuser system, TOPIC has a system license fee of $39,500, independent of the number of users. On a network, the server software costs $15,000. MS-DOS software costs $695, and the Sun workstation software costs $2,500.

2.13 XANADU

Project Xanadu [CONK87] proposes to convert all existing information to hypertext form. Ted Nelson, who coined the word hypertext, has developed a prototype on a Sun workstation. The back end of the system has been implemented in Unix and is available in several forms. A crude front end for the Xanadu system is also available and it runs on a Sun workstation. The system becomes more plausible with optical storage technologies such as CD-ROM. In Xanadu, storage space is saved by the heavy use of links. Only the original document and the changes made to it are saved. The evolving corpus is continually expandable without fundamental change. New links and windows can continually add new access pathways to old material. Fast proprietary algorithms render the extreme data fragmentation tolerable. A commercial version is not currently available.

2.14 ZYINDEX

ZyIndex [PERE87] is a text retrieval system developed by the ZyLab Corporation of Chicago, Illinois. They claim they had the first PC version of a text retrieval system back in 1983. Their

current software comes in three versions. Zyindex Personal ($95) indexes a maximum of 500 files containing up to 500,000 unique words, with one index per hard drive. Professional ($295) handles 5,000 files, and any number of indices. Plus ($695) deals with 15,000 text files, and any number of indices. Plus also works in a network environment.

Zyindex lets the user leave their text files wherever they happen to be on the system and in whatever format, without altering them. It can recognize a wide variety of word processing formats such as EasyWriter, Microsoft Word, MultiMate, PCWrite, Smart, WordStar, WordStar 2000, WordPerfect, and many others [PERE87]. Zyindex works by creating an index list of every word and number in specified files. It keeps track of what files each word is in and where each word is within each file. Common noise words are ignored. Because of this, each index occupies about 20 percent of the space of the original file. The maximum single file size is 64K, but that does not count the noise words. As a practical matter, it should handle files up to 100K. Also, one can build their own noise word list. It comes with a list of 145 noise words, to which the user can add up to 110 more. This gives a maximum of 255 possible noise words [BROW88].

The indexing program's speed is barely adequate. It took more than nine minutes to index a 32K file on a 4.77 Mhz PC with a hard disk. Once the index is set up speed is more impressive. A brochure claims it can search 15 megabytes for a single word on a PC with Motorola 80286 architecture in five seconds. The query language handles Boolean operators as well as proximity searching (find this word within so many words of that word). A search request can consist of up to 160 characters. An optional package, Zyfeatures ($95) that works with Plus and Professional, contains a thesaurus with 200,000 core words. Each core word can have up to 15 synonyms. The user must scroll through the list of core words and synonyms to select the ones to use for the search. This thesaurus can also be modified by the user.

ZyIndex runs on MS DOS machines or IBM PCs with at least 448K of memory. LAN versions are compatible with Novell, 3COM, Banyan, and Token Ring. Zyindex is primarily an indexing and searching tool. Documentation, ease of learning, ease of use, and support are all rated very good to excellent [PERE87]. This is probably the most impressive of the microcomputer based text retrieval systems that are reviewed here in Section 2.

2.15 AN UNNAMED TEXT RETRIEVAL SYSTEM

An article called "An Expert System for Searching in Full Text" [GAUC88] describes an experimental text retrieval system being developed by the Computer Science department at the University of North Carolina at Chapel Hill. The system is being

developed to help users locate relevant passages in large textual databases. Their expert system automatically reformulates contextual Boolean queries to improve search results and presents retrieved passages in decreasing order of estimated relevance.

Their system works with semantically unprocessed text and contains a knowledge base of search strategies independent of any particular content domain. The user interacts with the expert system in a high level query language. The expert system deals with the technical details of the textbase and works with the user to refine the query if the initial search is unsatisfactory. If the search produces too many passages, then the expert system reformulates the query by tightening constraints. If it produces too few, it reformulates the query by loosening constraints and/or expanding the search terms. When an appropriate number of passages have been identified, the expert system rank orders them by their probable interest to the user. During the process, the user remains an active participant in the search, but the system assumes responsibility for many of the details. Although similar to SPIRIT in many regards, this is only a prototype system with a limited thesaurus at the University of North Carolina. As of September 1988, the prototype system was not quite finished.

3. START and SPIRIT

In this section the focus is on two text retrieval systems, START and SPIRIT. It is believed that a combination of the features found in both of these systems will solve the information retrieval problems of NASA Public Affairs.

3.1 START

START [KATZ88] [MCLA89] (SynTactic Analysis using Reversible Transformations) seems to be the system with more features desired by NASA KSC Public Affairs than any of the others reviewed above. Yet there are still some problems with this system that would make it impractical to use on a daily basis.

START consists of several modules. An understanding module analyzes English text and indexes the knowledge contained within it into a knowledge base. The generating module produces English text from retrieved portions of the knowledge base. The user gains access to the knowledge base by querying it in natural language, and the system frames its response in English. The system has been under development for approximately 10 years by MIT's Artificial Intelligence Laboratory under the direction of Dr. Boris Katz. It runs on a special Symbolics machine using Common LISP. Later, it might be ported to other machines with Common LISP.

START claims to be domain independent. A simple process of lexical acquisition makes START adaptable to many different domains [KATZ87]. It analyzes sentences and parses them into 'T-expressions' ('T' for ternary), which summarize the syntactic structure of the sentence by its basic tripartite structure, that is subject/ verb/ object. There is a large rule base of 'if-then' rules, called 'S-rules' ('S' for syntax and semantics), which aid in the parse, and can be modified to meet the needs of any application. However, as with any known English language parser, it is unable to parse all of English. Hence, either new rules must be added to the rule base (START has this capability), or text in the database must be manually read and checked for sentences the parser will have trouble with. These sentences must then be changed. In addition, the words in the vocabulary of START are stored in a Lexicon along with detailed information for each entry. This information includes class membership for verbs (e.g. emotion-reaction verbs), inflection, gender, number, and part of speech. Similar to the set of S-rules, augmentation of the Lexicon is possible. Virtually every part of the START system relies on the Lexicon to accomplish its work. In the understanding module, the Lexicon is used to recognize embedded clauses, to construct kernel structures, and to build T-expressions [KATZ87]. In the generating module, the Lexicon is consulted when a noun or verb phrase is built, when a connective transformation is applied, and when a question is answered. More details on how the Lexicon is used can be found in [KATZ87].

If the text is suitable for the parser, START will perform the syntactic analysis, indexing, matching, resolving lexical ambiguities, and the retrieving of text necessary to generate an English answer. Details on the actual process can be found in [KATZ87]. This article discusses kernel sentences, converting kernel structures to T-expressions, transformation rules, embedded sentences, complex noun phrases, relative clauses, lexical ambiguity, forward and backward S-rules, as well as containing information on START's Lexicon.

One such database of text was developed for JPL (Jet Propulsion Lab, Pasadena, California) during the Voyager encounter of Neptune. This experimental database was used to test the robustness and accuracy of the START system by using it as a query facility for the news media and the space community. This text had to be modified for START to use it. It took a few days to set everything up completely, including the linguistic rule base [BROO89].

There was an enormous number of linguistic rules and pertinent facts about Voyager that had to be included. [BROO89] also notes that once the knowledge base was established, it was relatively easy to add some new text, as the JPL staff later added some short Public Affairs press releases. Only a fraction of the available knowledge set was incorporated into START. The approximate size of the ASCII text files was 300-400K [BROO89].

Response time was good, about two seconds for each question that could be answered. Questions sometimes had to be reformulated into the somewhat stilted version of English that START prefers to produce an answer. START is sensitive to how a question is asked, with a simple and direct question the best approach. One downfall was that the parser could not parse all the English text, hence each text used for input had to be carefully examined to see whether the rule base could parse or analyze it. Another problem was that occasionally new rules had to be added. These problems would seem to make START impractical for a large document, such as the shuttle manual.

Another application that JPL hopes to use START as a tool is in spacecraft sequencing [KATZ87]. Spacecraft sequencing is a process which involves designing, scheduling and programming the onboard activities of an interplanetary spacecraft as well as controlling its functions. The scientists' requests are coordinated into a sequence of activities for the spacecraft by a team of experts called the Sequence Team (SEQ). The SEQ uses a set of computer programs, the Mission Sequence Software (MSS), to perform this task. This software is very difficult to use, and JPL would like to develop an easier version to use to reduce the costs of a mission.

It is estimated that the current 25-30 member SEQ could be reduced to 10-15 members by letting requesting scientists interact directly with the MSS through a more user friendly workstation. A user could enter their requests in English and START could act as a translator to produce inputs for the MSS. Acting as an interface between the user and the various components of the MSS, START could convert English commands into the cryptic language that the MSS currently uses. This would also allow the experts to still use the cryptic commands if they so desire. Another possible function for START is as a query tool. Questions about spacecraft and subsystem states could be asked and responded to in English. It is hoped that START could be used to provide a friendly interface needed by novices for operating the MSS. An appendix in [KATZ87] contains some actual dialog with START using a 50 line Mars Observer sequence segment.

3.2 SPIRIT

The remainder of this report focuses on a software commercial product called SPIRIT (Syntactic and Probabilistic Indexation and Retrieval of Information in Texts) [SPIR86]. This system solves the deficiencies of the concordance and Boolean search based techniques by using a natural language query interface, and by using more accurate probabilistic retrieval techniques. It also has the ability to produce hypertext linkages automatically to allow the user to move from one revelant document to another revelant document. SPIRIT does this by using the keywords from a chosen document as the search

criteria for locating other related documents. SPIRIT creates an inverted file which is a list of tokens found in the database, along with the locations of each occurrence. The system scans the inverted file of the documents in its database, building an ordered list of candidate documents based on their semantic proximity to the query. Its search strategies are not domain dependent. It uses linguistic analysis and probabilistic models. SPIRIT can take a piece of text and link to other portions of text which are linguistically and probabilistically related to the original piece of text. This action simulates a human looking for pertinent information and represents a major activity of NASA Public Affairs personnel as they obtain answers to media questions.

The system is based on more than 15 years of research by French national research organizations. Some of the main features of the SPIRIT system which are related to meeting NASA's needs are [DRIS89] :

a. Automatic indexing of English text using both a linguistic analysis and a probabilistic model.
b. Queries are in full natural language English.
c. Answer text is ranked according to query relevance.
d. Hypertext browsing is available from a page of text to other relevant pages of text, and from one document to other relevant documents.
e. End-user interface and help assistance is available.
f. A 100,000 word English dictionary is included.
g. It has large database capabilities (up to four gigabytes).
h. It is available on various hardware systems ranging from the IBM PC, UNIX micro and minicomputers, to various mainframes (such as the IBM4381 at UCF).

SPIRIT can take an original text (e.g. a query) and determine a ranked list of documents which most likely are pertinent to the query. SPIRIT returns the document; thus, completely automating the search for relevant material where an answer to the query might be found. It also highlights the keywords in the retrieved documents to speed up the human task of scanning the retrieved text for an answer.

4. EVALUATION OF THE SPIRIT SYSTEM

SPIRIT needs to installed by a trained systems analyst. If someone who lacks this experience tries to install SPIRIT, problems will arise unnecessarily. Since SPIRIT was installed at the University of Central Florida, there was no systems programmer dedicated entirely to this task. What systems help in Computer Services could be found was used, as they were busy with many other tasks. Computer Services' systems personnel were not the direct contacts for computer assistance at the university.

Also, little support was received from the Systex company of France which made the system. This happened because the SPIRIT version obtained was given to Dr. Driscoll for free for demonstration purposes. Dr. Driscoll and this author have never installed a system like this and have no systems background up to now. Due to these factors, probably more difficulties were encountered than a company who purchased the system and had it professionally installed would have encountered. Some of these problems are described below.

4.1 PROBLEMS LEARNING SPIRIT

SPIRIT was created in France, so obviously a major difficulty was the language barrier. The user manual was in French, as were most of the menus. In the query portion of SPIRIT, the menus become English for querying English databases. A translator was hired to translate the user manual and to help translate some of the more commonly used menus. The manual was very poor, leaving one to guess how many features worked. For instance, at least two weeks were spent figuring how the update and delete documents features worked. Two or three fax were sent to France to get some of the unresolved questions answered. This added to the delay in learning SPIRIT, and to the total time required to index the shuttle manual.

Some problems were discovered with storage on the G disk work area. These problems will be further addressed in the section below entitled "Problems with Database Management".

One of the results of this project was the creation of an English version user manual. This manual should help one get acquainted with the main features of SPIRIT. It is not intended to be comprehensive, but is hopefully more helpful than the translated original French user manual. It is included in Appendix B of this report.

4.2 PROBLEMS WITH DATABASE MANAGEMENT

Another problem area was that of managing the databases. SPIRIT requires a temporary disk G (t-disk) anytime the system is used. It uses the most space on this disk during the indexing of a database. The shuttle manual was expected to take more room than it actually did on this disk. Unfortunately, there was no way to tell the maximum amount of room this particular database needed during indexing because SPIRIT deletes files from disk G as it indexes. The SPIRIT manual suggests that the work area on disk G be about 40 times as large as the original (FIIN) file when indexing a database. At the end of indexing the shuttle manual, 8180K of storage was used on disk G. Because of the unpredictable size of this work area, it was decided to allocate more cylinders than Computer Services at UCF said could be

allocated as a t-disk. Because of this, the G disk had to be made a permanent disk while the manual was being indexed. Special permission had to be received to do this.

The next problem is not related to creating databases, but related to multiple users accessing SPIRIT. Under the VM operating system which is used at UCF, only one user can have read/ write access to a disk at one time. SPIRIT requires each user have read/ write access. Because of this, only one user can be on SPIRIT at one time under VM. This however is not the case if one uses the MVS operating system (see section "Recommendations to NASA" below). To get around this problem, two copies of the entire SPIRIT software system had to be made so it could be available to two users. Again, problems with resources and accounting were created, resulting in additional time used to find out a solution to this situation. Mostly, these problems were related to taking too much storage. The entire SPIRIT software took 80,844K on the mainframe with no databases attached. The breakdown was: disk A, 776K; disk B, 16,716K; disk C, 16,920K; disk D, 40,432K; and disk G was allocated 10 cylinders or 6,000K. Due to many other users being on the system, special permission had to be obtained to duplicate this software. Again, this would be unnecessary on a machine running the MVS operating system.

4.3 CREATION OF THE SHUTTLE MANUAL DATABASE

Creating the shuttle manual database was this author's first attempt at using SPIRIT. It was a frustrating experience which could be attributed to three main factors. First, there was the newness of the system. Secondly, there was the lack of adequate documentation complicated by a language barrier. Finally, there was the large size of the shuttle document.

It took several weeks to learn enough of SPIRIT to create the shuttle manual database. Then it took some additional weeks to learn how the delete and update menu choices worked. Some of the less frequently used features of SPIRIT are still being learned at this writing.

It was discovered that the size of the original shuttle manual text file was enlarged when it was saved in a fixed record length of 80. The file increased from about 2700K in its original form, to 4308K when saved on the mainframe in this format (F80). The total database, including the original text file, took 18,420K. The manual was automatically marked and formatted into 4902 documents for SPIRIT by a PC program written by this author in Turbo Pascal. From there it was sent to the mainframe from the LAN (Local Area Network) for SPIRIT to index. The manual took 3.5 hours to index. The G disk work area had to be enlarged to index this document (the G disk had 7 files totaling 8180K at the end of indexing).

Other software limitations noted in the SPIRIT user's manual include a maximum line length of 78 characters, a maximum number of fields per database of 32000, a maximum size of a database of 700 megabytes, and a maximum number of documents per database of over 2.1 billion (2^31-1 to be exact). Also, the input file must be contained on one disk.

A large portion of the indexing process involved sorting. The original version of SPIRIT used a sort package that sorts records in memory. The package shipped with SPIRIT is a standard sort utility that runs on most IBM mainframes. It can sort no more than about one half million records. Due to the large size of the shuttle database, SPIRIT could not handle sorting the large number of records being created, and would crash every time an attempt was made to index. Finally, after some effort, the problem was located. With the help of the Computer Services' staff, particularly Mrs. Mary Garner, the old sort package was replaced by SyncSort. SyncSort can handle a much larger number of records since it also uses disk space as well as memory during a sort. It took about 3.5 hours to index the shuttle manual after this problem had been corrected. This was about one third the estimated amount of time of 12 hours based on smaller databases that had been created. Most of this decrease could be accredited to using SyncSort.

After overcoming the memory problems and the sorting problems, the shuttle database was finally created. It is estimated that the total time required for a user to create the database (provided there were no technical problems) was about 7.5 hours. This time estimate assumes that one knows the system well and everything is working properly. It assumes that the text had already been created and saved as a text file on a medium such as 5 1/2" disks.

4.4 CREATION OF THE GALILEO DATABASE

A smaller database was created for demonstration purposes for the October 12th launch of STS-34. This particular mission involved sending the Galileo space probe to Jupiter. The database consisted of three parts, a press release, a fact sheet, and a contingency plan. The text was in a different format than the shuttle manual, so it was decided to mark it manually for SPIRIT since it was fairly short.

The entire setup time was about five hours with only 20 minutes of this time devoted to SPIRIT doing the indexing. The remaining time was devoted to formatting the text. The 170K file became 244K on the mainframe, with the entire database being 2468K, including the 244K file. Twenty cylinders (12 megabytes) were allocated on disk G. At the end of indexing, disk G had 11 files using 2340K (or about 20% full). The creation of this

database was problem free, except for the text formatting problem, which was unrelated to SPIRIT.

The fact that two different texts were received from NASA in two different formats showed the need for some standardization of text creation in the NASA organization. This time however it was because the shuttle manual was created by an outside contractor, Rockwell.

Most word processors have the ability to save files as plain ASCII text, and to eliminate headers and most control characters. However, they do not all format the text in the same fashion. For instance, one word processor might save a paragraph as all text, with no linefeeds or returns until the end of the paragraph, while another has a linefeed and/or carriage return at the end of every line. Sometimes even the order of linefeeds and carriage returns is reversed. Due to the unpredictable nature of these markers, it is difficult to recognize the boundary of a paragraph for any word processor. This could be partially resolved if only one or two word processors were used. Additionally, paragraphs should be separated in a standard fashion, such as having one blank line between paragraphs. Such standardization would help cut the time used in text formatting.

4.5 DEMONSTRATION AT THE PRESS SITE DURING THE LAUNCH OF STS-34

Unfortunately, STS-34 did not go off October 12th as planned, but was delayed six days. Dr. Driscoll and this author decided to go to the press site anyway, since there would still be press present to ask questions. Also, it would not be as hectic as it would be on a launch day.

This author had the opportunity to talk with Mrs. Kay Grinter, librarian at the KSC press site, and with Mr. Charles Redmond, Information Specialist, Office of Space Science and Applications, NASA Headquarters, Washington, D.C.. Both people gave some helpful information which will be condensed in this section.

Mr. Redmond was able to collect about two dozen questions that had been posed recently about the mission. These questions are listed at the end of this section. It was soon discovered that not all the questions had answers in the two databases that had been set up. For some of the questions, it was known that the answer was present in one of the two databases. Rephrasing of these questions was necessary so that the keywords that were in the answer, were in the question. It would have been helpful if the English version had synonym recognition. About one third of the queries posed actually responded with text that would answer the question.

One annoying feature was that SPIRIT would occasionally find a class of documents with all or most of the keywords contained in the query. But when one went to look at those documents, the topics of those documents were unrelated to the meaning of the query. It was disappointing to have a document to answer the query based on finding a lot of keywords in it, yet the document did not answer the query. The retrieval process is going to have to associate some meaning to the retrieved text, possibly through the use of thematic roles. The problem of unrelated meanings and the inability to find text that contained the answer without rephrasing the query, were the main disappointments that were discovered while using SPIRIT at the press site.

When text was found that answered a question, the observers were impressed with the speed of retrieval, even though a 1200 baud modem was being used.

One question for which an answer was desired was "How much time on average does Public Affairs personnel spend looking for an answer to a question?". This question did not have a clear answer. At launch time, Public Affairs personnel come in from all over the country. Some have many years of experience and can answer many questions from memory. Most of the staff observed during this launch had their own large notebook or briefcase of information that would help answer questions. This they could quickly access since they were so familiar with it. If one person does not know the answer, he asks another and another until a satisfactory answer is found.

For the more difficult questions that need more research, the librarian, Mrs. Grinter, is asked to do some research. She said that she will spend whatever time she has available to track down an answer. She remarked that she may track a question off and on for days before giving up. She would probably benefit the most from a SPIRIT like system, since she gets most of the obscure questions. As one can see, there is really no such thing as an average time per se.

Mr. Redmond said that it has only been since the Challenger accident (January 1986) that documents have been kept for the long term in an electronic form. The problem is there is no agency wide policy on how to keep these documents. Most are on small floppies scattered throughout the many departments of NASA, while a few are on disk packs, or magnetic tape. Some standardization in word processors has been implemented, with most departments now using WordStar 2000. However, other documents that are contracted out, such as the shuttle manual made by Rockwell [NASA89], use WordPerfect on the IBM PC. This complicates the task of text formatting and marking that is done to prepare a database for SPIRIT. The text formatting and marking program would have to be modified for every distinct text format. Two different word processors might save text in the same format, but may not. Mr. Redmond has indicated that the

NASA standard is to use WordStar 2000, and format the ASCII text file so EVERY line ends with a linefeed (#13), then a carriage return (#10). NASA is trying to implement this policy agency wide. Other formats would have to be dealt with on a one by one basis. Mr. Redmond is aware of the problems this creates.

Mrs. Grinter and Mr. Redmond are painfully aware of the lack of data organization in the agency. A large amount of time is wasted looking for information that is probably out there, but cannot be found because it is lost or misplaced. As mentioned, electronic textual information is scattered throughout the agency. One attempt was made in 1983 to start centralizing what electronic text was available in one mainframe. As a result of the processing time this task took, the department that was using the mainframe almost had to close down since it had trouble getting any computer time. According to Mr. Redmond, the project was finally scrubbed. He said the agency needs a dedicated machine (mainframe) given to the task of maintaining these text databases. Currently, there is no such machine available, and no plans yet to buy one. This should be considered if NASA decides to use SPIRIT on the Amdahl that they currently are using for other tasks. There is a danger the same problem could happen again, particularly after many databases are added, and many users begin to access SPIRIT (or any other text retrieval system).

A dedicated machine should be strongly considered if NASA plans to organize the overload of textual information being produced. One department should have the authority to set a standard for producing text and collecting text from all other NASA departments. Also, they should have the power to enforce this standard agency wide so the databases created can be used effectively by everyone, not just Public Affairs.

QUESTIONS GATHERED AT THE PRESS SITE

1) How long do the solid rocket boosters burn?
2) How much power or thrust does the shuttle produce?
3) How many gallons of oxygen and hydrogen are in the external tank?
4) How many pounds of plutonium are in each RTG?
5) What type of radiation is produced by plutonium 238?
6) How heavy a payload can the shuttle carry? (rephrased to: What is the lift capacity of the orbiter?)
7) What is the longest shuttle mission to date?
8) What are the weather constraints for a RTLS (return to launch site) abort?
9) How often can a shuttle be fueled, detanked, and refueled?
10) What is the fuel used in the solid rocket boosters? (rephrased: What are the solid rocket boosters fueled with?)
11) How high can the shuttle fly? (rephrased to: What is the nominal altitude that the shuttle flies at?)
12) How long does it take to refurbish the orbiter between flights?

13) What are the radio frequencies or bands used by the TDRSS (tracking and data relay satellite system)?
14) What are the weights of Galileo, the Galileo probe, and the IUS (inertial upper stage)?
15) How much thrust is produced by the IUS?
16) What are the dimensions of the cargo payload bay?
17) What was the cost overrun for the Galileo project?
18) Why didn't NASA use another power source for the Galileo mission?
19) What security precautions have been taken against the nuclear protestors?
20) How will the replacement of the main engine controller affect the launch of STS-34?
21) Is Galileo the heaviest payload ever on the shuttle? (can be answered by looking at the results of questions 6 and 14)
22) What type of accident would cause a release of radioactive material?
23) If the orbital tours around Jupiter are cut from 10 to 8, will Galileo still fly by all of Jupiters' moons?
24) What is the velocity of the probe at entry into Jupiter's atmosphere?
25) What is the temperature of the probe during entry into Jupiter's atmosphere?

RESULTS

Ques. #	Time spent(min/sec)	Doc # of answer	# docs browsed
1	00:45	s842	1
2	01:45	s919(PA)	4
3	10:00	N/A	
4	10:00	N/A	
5	01:00	s34,s35	3
6	05:00	s3979,s3976(PA)	6
7	01:00	s4470	1
8	10:00	N/A	
9	10:00	N/A	
10	01:00	s3094	2
11	01:15	s83	2
12	10:00	N/A	
13	03:00	s1962,s1887,s1898	6
14	00:30	g217	1
15	00:45	g183	2
16	00:45	s4588	3
17	02:15	N/A	
18	01:00	g7,g25	2
19	02:15	N/A	
20	01:45	N/A	
21	05:30	N/A	
22	06:45	g86(PA)	15
23	03:45	N/A	
24	02:00	g141	5
25	01:15	g141	2

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KEY: Time is in minutes and seconds. The maximum time spent on any one question was 10 minutes. A 's' before document number means from the shuttle database, and 'g' means from the galileo database. 'N/A' means 'not available', or 'not answerable' from the information in the two bases. 'PA' means 'partial answer'. Some questions had to be rephrased as noted next to the question.

COMMENTS: More data needed to be available to answer the wide range of questions being asked (10 of 25 had could find no related text). The lack of synonym recognition created many problems in retrieving text and in asking questions without rephrasing the question (e.g. #11). The average time spent on the 15 questions that had any documents that answered (at least partially) the question was one minute and 51 seconds. This user browsed an average of 3.67 documents (each usually one or two screens).

4.6 ADDITIONAL INFORMATION ON SPIRIT RETRIEVAL TIMES

An experiment regarding retrieval times was performed by Jan Smith as an undergraduate independent study project. A sampling of 35 questions about the shuttle manual were chosen from a larger list of 100 plus questions. Search times for the answer, as well as the number of paragraphs scanned, were recorded. This was done by both the SPIRIT system and by doing it manually by looking through the shuttle manual's hard copy. The questions asked, as well as the results of asking each question, can be found in Appendix A.

The results indicate an average search time of two minutes and two seconds using SPIRIT, versus an average search time of nine minutes and 55 seconds doing it manually. The average number of paragraphs scanned using SPIRIT was three, versus 13 paragraphs scanned searching manually. One particular question was not found in the manual. SPIRIT was able to indicate this in one minute, so the question was not looked up manually. The time for this search of a question that did not have the answer in the manual was not included in the average time. Additionally, there was an agreed upon maximum limit of 30 minutes for searching by hand in the manual. If the answer was not found, this was indicated, and the time recorded was 30 minutes. Because of these two reasons, the average time of nine minutes and 55 seconds doing the search by hand is really underestimated. This was an average time based on finding the answer in the manual, provided the answer was there in the first place.

All that can be stated is that for this particular person, the manual search time was at least nine minutes and 55 seconds on average. This was an increase of at least seven minutes and 53 seconds over using SPIRIT. Obviously, these times will vary according to the familiarity of database, and the subject knowledge of the person answering the question. It may also be

noted that SPIRIT was faster than a human in finding the answer in 27 of the 35 questions.

Because the data was only collected by one person, no statistics can be inferred, such as a confidence interval for the difference in the mean retrieval times, or a hypothesis test for the difference in the mean times. However, the following experiment has been suggested by Mrs. Julie Wildman of the Statistics Department at UCF.

Let n1 different people look up the same set of questions using SPIRIT and record the times it takes them to find an answer. Let n2 different people look up the same set of questions as used by the n1 people. Record the times it takes them to find the answers looking through the manual by hand. Preferably, n1 should equal n2, and should be at least three, to around six. For those looking up the answers by hand, allow them to stop looking after 30 minutes, making a notation of stopping before finding the answer. Randomize the order of the questions given to the n1+n2 people. Perform a nonparametric statistical test on the data collected, and test whether the average computer retrieval time is statistically less than the average human retrieval time. Also, one can calculate from this data a confidence interval for the difference in the means of the two retrieval times.

The result of such an experiment would show that if the answer is present in a database, then SPIRIT on average would find the text faster than a human could. The data obtained from this one individual indicates that for her, SPIRIT saved her time retrieving the needed text to answer a question.

5. RECOMMENDATIONS TO NASA KSC PUBLIC AFFAIRS OFFICE

In this section, software and hardware recommendations are given to NASA Public Affairs.

5.1 SOFTWARE SUMMARY AND RECOMMENDATIONS

NASA Public Affairs should avoid a manually linked hypertext system since links between related texts must be inserted manually. This would be unwieldy even for a full time hypertext expert. SPIRIT requires little document preparation, and simulates hypertext links by probabilistic models based on keywords. The English version is not quite as sophisticated as the French version as of now, but the Systex Corporation plans to release an English version that will be as good as the French version. These differences are mainly technical and are not noticeable to the user. Presently, the English dictionary is not

as large as the French version, and the current English version does not have a thesaurus implemented.

SPIRIT is a commercial product that is available now, and could be in use within a few months. It solves half of the NASA Public Affairs problem in answering media questions. It retrieves text that would most likely answer the questions asked. Additional research will need to be done to add an interface to actually answer the question in natural language. Perhaps a START-like interface could be developed to perform this task, as this system seems closer than the others to meeting NASA's needs.

It is hoped that NASA will extend research in this area under future grants to expand SPIRIT to answer the questions posed to it. In the meantime, NASA could install SPIRIT and use it now for text retrieval.

The experiences at the press site during the launch of Galileo and the studies of text retrieval times, indicate that KSC Press Site personnel could save time and effort in answering media questions with SPIRIT. Most of the deficiencies could be attributed to three areas. First, there was a lack of enough material in the two databases to answer the wide variety of questions asked. Secondly, there was the lack of synonym recognition in SPIRIT. Thirdly, there is a lack of textual meaning built into the system. This last problem might be solved by combining some of the features of START into SPIRIT. This will take some further research to implement. Synonym recognition should be available in a more recent English version of SPIRIT due to be released soon.

5.2 HARDWARE RECOMMENDATIONS

First, the hardware environment that is used at the University of Central Florida for SPIRIT is an IBM Group 2 mainframe with 32 megabytes of memory and 16 gigabytes of disk storage. It uses the VM/CMS (high performance option 5.0) operating system (VM/CMS means virtual machine/ conversational monitoring system). Over 150 IBM 3178, 3278, and 3279 terminals access the mainframe on campus.

SPIRIT can run under VM or MVS (multi virtual subsystem) operating systems in the mainframe version. Under VM only one user can have read/ write access to a file at a time. Because SPIRIT requires read/ write access to query databases, only one user can be on SPIRIT at a time under VM (unless duplicate copies of SPIRIT and its databases are available, which waste storage resources). Because of this, the recommended operating system to run SPIRIT is MVS which will support multiple users having read/ write access to a file.

According to Mr. Bud Sims, systems analyst at NASA KSC Headquarters, NASA has an Amdahl 5890 running MVS/XA (extended architecture). MVS/XA is an extension of the MVS/SP operating system. Amdahl computers are made with IBM mainframe compatibility in mind. The Amdahl 5890 is compatible with the IBM 3090 class of mainframes, and is rated at 18.5 mips (million instructions per second). This computer is two and one half to three times faster than the IBM 4381, which is rated at 5-6 mips. NASA currently has 62 gigabytes of secondary storage on this mainframe. Mr. Sims felt confident that SPIRIT will run on NASA's current Amdahl mainframe under MVS. This information also seems to agree with that gathered from the Amdahl Corporation local office in Maitland, Florida. Again, it is emphasized that a dedicated machine should be carefully considered.

Additionally, there is currently a version of SPIRIT that runs in the Unix environment on a SUN workstation. SUN workstations come with between four and 24 megabytes of internal memory. They can access up to one gigabyte of secondary storage. This one gigabyte is a practical limit, but may be extended slightly if some second party storage devices are used. Most SUN workstations use a Motorola 68020 processor, and they are rated between 1.5 and 10 mips, depending on what benchmark is used [PRIC89]. See [PRIC89] for a description of problems created when comparing mips between machines with different processors.

Also, there will be a PC version of SPIRIT released approximately November, 1989. However, NASA should not purchase a PC version for numerous reasons, unless some careful testing is performed. SPIRIT is I/O intensive and requires a lot of CPU time when indexing a database. Even with hard drives for microcomputers decreasing access time down to around 30 milliseconds, compared to 20-25 milliseconds for mainframe disk drives, it is believed that the overall access time, coupled with the data transfer rate, would be much lower in a mainframe environment. Also, the IBM4381 has a 32 bit word size, versus 16 bit for most PCs. The larger word size, along with higher processor speeds, would result in larger overall throughput in the mainframe environment. One way to compare the PC version with the mainframe version is to obtain the PC version and try indexing the shuttle manual as previously done. Then the indexing times should be compared. Query times could also be compared on both systems. This should be done before NASA decides to use the PC version.

In general, more secondary storage is available in a mainframe versus a PC. For instance, there are PC hard drives that can store 700 megabytes. Most PCs have one controller card that can have two drives connected to it, for a maximum of 1400 megabytes of secondary storage. As one can see, this is over one gigabyte with the latest technology, while mainframe disk drives can be many gigabytes. One such IBM disk drive has 7.56

gigabytes of storage. Microcomputers can overcome this secondary storage limitation in a LAN.

Novell has a LAN network (386 version) available that in theory can access a terabyte of storage. One terabyte is approximately 1000 gigabytes, or exactly two to the 40th power bytes. Also, some operating systems limit how much secondary storage one can access. DOS is limited to about 20 megabytes in versions before 4.0. Usually, this limit is much higher in a mainframe environment than in a PC environment. The factor of addressable secondary storage is losing importance as many microcomputers can now address comparable amounts of memory. It should be noted that SPIRIT takes approximately 80.85 megabytes of storage just for the software itself. Also, a large amount of secondary storage is needed for the working files that SPIRIT creates while indexing.

The SPIRIT user manual cautions that the working files may be as large as 40 times that of the entry file. These working files however are later removed when the indexing is complete. As an example of the storage required for one database after the indexing was complete, the shuttle manual entry file was 4308K, and the finished base (indexed database) was 14,112K.

Systems personnel at the Computer Services office at the university recommend that any database over 5000 records (lines) be processed on the mainframe. Certainly, the shuttle manual alone would fall in this category. For these reasons, it is suggested that NASA use SPIRIT on a mainframe system.

5.3 CONCLUSION

Since the PC version of SPIRIT is not available at the writing of this report, it is very difficult to make any statement about its expected performance. The only definitive answer would come if the PC version was obtained and tested using the same database (shuttle manual) that was prepared with the mainframe version. Indexing times, as well as query retrieval times, should be compared. Since this is the first release in this format, there is the possibility of software errors that would need to be removed. If the Amdahl mainframe will run SPIRIT under MVS, then SPIRIT could be temporarily used on this machine until a dedicated computer is obtained. Hopefully, SPIRIT would not take too much computing time from other jobs.

NASA could also consider using the mainframe version of SPIRIT to index the databases, and using dedicated microcomputers to query the databases at the press site with the PC version of SPIRIT. Since databases are not created very often, the Amdahl mainframe would not be tied up for extensive amounts of time with SPIRIT. Most of the processing time taken by SPIRIT on a daily basis is during the query process. According to the Systex

Corporation, the creators of SPIRIT, databases can be created with one version of SPIRIT and queried on another version. This strategy would save the expense of buying a dedicated mainframe for SPIRIT to use.

NASA should try to standardized the way that they create text files as much as possible, especially if these files are to be used in the SPIRIT system. Most of the database creation time is tied up in preparing and marking the documents for SPIRIT. Some of this preparation can be automated, but is difficult when documents are coming from different word processors, as not all word processors save ASCII text files using the same conventions. Limiting the formats to one or two versions would help save a large amount of time.

Some caution also should be given at this point. SPIRIT was often frustrating to use, even for the systems personnel at UCF, since its documentation was so poor and in French. If this system is installed at the Kennedy Space Center, further documentation should be created for NASA Public Affairs personnel to use. The User's Guide included in this report is a good start. Some consideration should be given to translating the remaining French menus, and some of the code (particularly comments). Perhaps the Systex Corporation would help in this effort.

SPIRIT's ability to retrieve text was impressive. A minimal amount of document preparation was involved before indexing. SPIRIT was able to retrieve documents moments after indexing. Its highlighting of keywords aids in locating text that could answer the query. It is flexible in the way queries may be posed, allowing Boolean or natural language queries. Even one document may be used to search other related documents based on the keywords found in that first document. SPIRIT puts the documents into classes it feels will most likely answer the query, helping the user to decide which classes to view. Most practical of all, SPIRIT is available now, it is not a prototype. SPIRIT can be used now while further research is completed that would add a START-like interface to create natural language answers from the retrieved portions of text.

APPENDIX A

QUESTIONS AND RETRIEVAL TIMES

By Jan Smith

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APPENDIX B

INSTRUCTION MANUAL FOR CREATING DATABASES WITH THE SPIRIT SYSTEM

By Mark A. Clark

Results of finding shuttle answers in Spirit:
(ordered by question number)

	Answer found?	Search Time	Number of documents read
1)	found	1 minutes 45 seconds	1
2)	found	1 minutes 45 seconds	1
3)	found	1 minutes 45 seconds	2
4)	found	2 minutes 0 seconds	3
5)	found	1 minutes 30 seconds	2
6)	found	2 minutes 0 seconds	3
7)	found	1 minutes 30 seconds	1
8)	found	3 minute 0 seconds	3
9)	found	1 minutes 15 seconds	1
10)	found	1 minute 15 seconds	1
11)	found	4 minutes 30 seconds	11
12)	found	1 minutes 0 seconds	1
13)	found	1 minute 0 seconds	1
14)	found	2 minutes 45 seconds	6
15)	found	2 minute 30 seconds	6
16)	found	1 minutes 0 seconds	1
17)	found	1 minutes 30 seconds	1
18)	found	1 minutes 0 seconds	1
19)	found	2 minutes 0 seconds	2
20)	found	2 minutes 15 seconds	5
21)	found	1 minutes 0 seconds	1
22)	found	2 minutes 0 seconds	1
23)	found	3 minutes 0 seconds	5
24)	found	1 minute 30 seconds	1
25)	found	3 minutes 30 seconds	11
26)	found	3 minute 45 seconds	9
27)	found	1 minutes 15 seconds	1
28)	found	2 minute 0 seconds	2
29)	found	3 minutes 0 seconds	4
30)	found	2 minute 45 seconds	6
31)	found	3 minutes 30 seconds	5
32)	found	1 minutes 15 seconds	1
33)	found	1 minutes 45 seconds	1
34)	found	1 minute 15 seconds	1
35)	not found	1 minute 0 seconds	0*

*Could determine in one minute that answer was not in the book. Notice that the word "color" was not found as a keyword.

Average search time = 2 minutes 2 seconds

Average number of documents read = 3

Results of finding shuttle answers in the book:
(ordered by question number)

	Answer found?	Search Time	Number of paragraphs read
1)	not found	30 minutes 0 seconds	30
2)	not found	30 minutes 0 seconds	28
3)	not found	30 minutes 0 seconds	38
4)	found	3 minutes 0 seconds	3
5)	found	8 minutes 30 seconds	12
6)	found	7 minutes 45 seconds	4
7)	found	4 minutes 0 seconds	4
8)	found	1 minute 30 seconds	3
9)	found	13 minutes 30 seconds	28
10)	found	1 minute 45 seconds	7
11)	not found	30 minutes 0 seconds	37
12)	found	4 minutes 30 seconds	5
13)	found	1 minute 30 seconds	2
14)	found	14 minutes 0 seconds	8
15)	found	1 minute 0 seconds	2
16)	not found	30 minutes 0 seconds	36
17)	not found	30 minutes 0 seconds	41
18)	found	3 minutes 45 seconds	6
19)	not found	30 minutes 0 seconds	45
20)	found	2 minutes 45 seconds	4
21)	found	2 minutes 30 seconds	2
22)	found	2 minutes 0 seconds	4
23)	found	4 minutes 15 seconds	4
24)	found	1 minute 15 seconds	1
25)	found	14 minutes 30 seconds	24
26)	found	1 minute 30 seconds	3
27)	found	7 minutes 45 seconds	9
28)	found	1 minute 45 seconds	5
29)	found	3 minutes 45 seconds	7
30)	found	1 minute 30 seconds	3
31)	found	2 minutes 45 seconds	10
32)	found	13 minutes 0 seconds	30
33)	found	2 minutes 0 seconds	2
34)	found	1 minute 0 seconds	1
35)	(answer not in book)		

Average search time = 9 minutes 55 seconds

Average number of paragraphs read = 13

by Jan Smith 89/10/10

Shuttle questions:

1) What is the maximum cargo weight the shuttle can carry?
2) How far can the shuttle transport cargo from the earth's surface?
3) What has happened to the Enterprise?
4) How many years of education are required for astronaut candidates?
5) What is the total weight of the shuttle?
6) How thick is the window of the shuttle?
7) How many gallons of liquid hydrogen fuel can the storage tank hold?
8) What type of liquid fuel is used on the shuttle?
9) What is the descent rate of the shuttle during landing?
10) How long is the mechanical arm used for payload deployment?
11) What are the dimensions of the cargo area in the shuttle?
12) How is waste disposed of?
13) Have there been astronauts picked from minority groups?
14) What is the total number of times that the shuttle has been launched?
15) What type of food do astronauts eat during a shuttle mission?
16) What is the orbiter's velocity while in orbit?
17) What is the maximum acceleration of the shuttle during launch?
18) What is the maximum touchdown glide speed of the shuttle?
19) How many pounds of thrust do the SRB booster rockets generate during liftoff?
20) What is the maximum fluid fuel flow rate during launch?
21) How fast does the crawler or transporter travel?
22) At what altitude and speed must the pilot throttle back during ascent?
23) How many general purpose computers are on board the shuttle and what functions do they serve?
24) What is the new design of general purpose computers like on board the shuttle?
25) What is the total number of tiles that cover the orbiter for thermal protection during reentry?
26) When did the first space shuttle launch occur?
27) How long is the runway at a shuttle landing facility?
28) What type of glass is used for the windows to withstand the pressure of flight?
29) What is the total amount of RAM available in the shuttle's general purpose flight computer?
30) What material are the heat shield tiles composed of?
31) What type of computer guidance and navigation system does the shuttle use during reentry and landing?
32) What is the maximum power available to the payload area?
33) Are there emergency escape procedures to jettison the crew members out of the shuttle?
34) Where do the crew members sleep on the shuttle?
35) What is the color of the external tank? (no answer)

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UNIVERSITY OF CENTRAL FLORIDA

COLLEGE OF ENGINEERING

PROJECT 2B - NASA GRANT NAG10-0058

Memory-Based Reasoning for Advanced Launch Operations

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Memory-Based Reasoning for Advanced Launch Operations

This document is a record of the findings that the UCF Memory-Based Reasoning for Advanced Launch Operations research team has developed in the investigation of the use of memory-based reasoning techniques to capture and process knowledge in an advanced launch scenario. A number of different paths were explored and all yielded useful results.

Background

Memory-Based Reasoning is a form of automated reasoning that uses the recall of stored events from an associative memory for inference and deduction. An associative memory (store) is nothing more than a memory that recalls based on paired symbols that have no address sequencing restrictions as is found in the linear memories of common computer systems. A key feature of associative stores is that the detection of identical or similar storage items from multiple addresses occurs in parallel. The associative memory is parallel by design and implementation. In Memory-Based Reasoning, a basic assumption is made that the cerebral reasoning functions of higher-order animals is an associative process where event and data inputs associate to learned or collective emergent responses. A collective emergent response is a novel reaction that was not learned. For example, if an associative system learns that apples and oranges are fruit by reason of their spherical shape, it would associate fruit with anything spherical. The refinement of distinguishing a toy ball from a piece of fruit is determined by the amount of information, or robustness of feature selection, available to the system. At least this is the theory. Our approach involves providing a significant amount of data to an associative system under a tightly constrained input and output subsystem to see if novel associations will emerge. The target platform for this data is the launch operations system.

Artificial Neural Networks (ANN's) were chosen for the development of the associative store because they are loosely based on animal cognitive systems and they most readily perform as associative memories. The following discussion addresses the specific development of our ANN model and the restricted domain scenario developed to demonstrate the memory-based reasoning approach.

Artificial Neural Network Model

Our initial goal was to create an artificial neural network (ANN) that would demonstrate learning. The modelling system chosen for this study is a commercial product called the Cognitron by Cognitive Software. The Cognitron runs on an Apple Macintosh graphic workstation and is capable of modelling any neural process based on the schema shown in Figure 1.

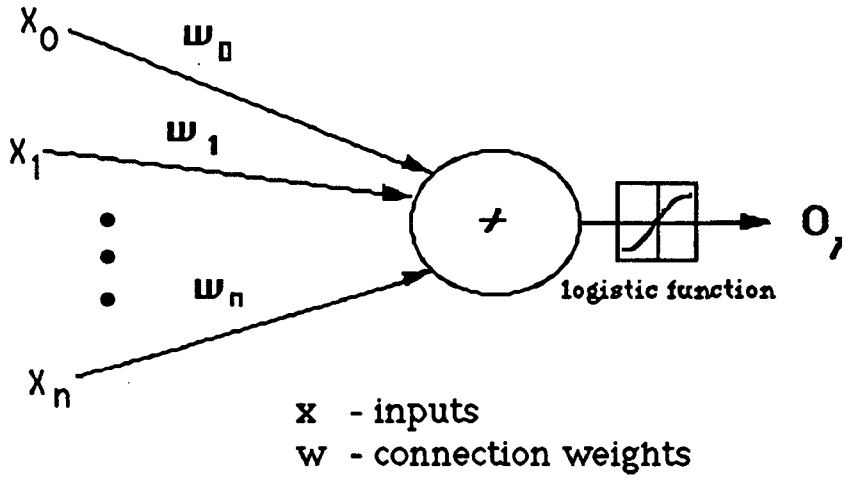

Figure 1. Cognitron Model Node

The Cognitron uses a graphic interface that allows the user to specify the schematic layout of the neural system using screen icons representing nodes in the network. Interconnections are defined by arcs drawn between the nodes. Internally, the Cognitron represents each node, the system interconnectivities, the weights, and the activation functions or logistics in Lisp. The user may access this Lisp code using a built in editor. In addition, the code my be output to a file and used by an external Lisp compiler for standalone neural processing. To perform the associative learning function for our purposes, a simple model was to be constructed having the following characteristics:

- An input layer with three numerical inputs (These nodes would read the input data).
- An output layer with three numerical outputs (These nodes would output the resultant data).
- A middle layer connecting the input with the output (This is what is referred to as a hidden layer).

- An output window (This would allow the result of the output nodes to be shown to the user).

- Several system nodes that take care of the functions necessary to allow the normal operation of a neural network.

The process that the network performs to output a result is called Forward Propagation. This means that the inputs propagate through the network in a forward direction, with calculations occurring as depicted in the model diagram in Figure 1, above. The algorithm for this process is outlined below.

First, the input layer receives input data from a file or other input device. This input is in numerical format, or is converted to numerical format before being placed into the input nodes. Each input node in the input layer receives a single input value. At the same time, the nodes in the target layer receive their input values. These values are the values that the user expects to see on the output layer when the network is finished and these values are referred to as the *expected values*. All the functions of the input layer and the target layer are performed in one time interval, called a *tick*. This clock time is maintained by a special system node called the Clock. Its job is to count from 1 to 5 consecutively, with each number representing a tick. The whole process from 1 to 5 is called a network cycle.

After the first layer has all the input data, the next step is to propagate this information to the next layer. The network performs this by allowing all the nodes in the second layer to add up all the values of the input layer multiplied by their individual connection weights. These weights are numbers that represent the connection strength of one node to another. Each layer (except the input layer) has these weights on their inputs. After these weighted inputs have been added together, they are sent to the logistic function. The logistic function used is as follows:

$$\text{OUTPUT} = \frac{1}{(1+e^{(1-\sum \text{WEIGHTED INPUTS})})}$$

This logistic function is performed on each middle layer node to compute its output. Once this process is performed for each node in the middle layer, this tick is completed.

The next tick performs the above process on the output layer, using the middle layer outputs as its inputs. After the logistic function is performed on these weighted inputs, the final network outputs are now known. These values are placed into the output window.

On the next clock tick, the nothing is performed. This is a settling period that allows the values of each of the nodes to be observed without having them change. In future models, this tick can be eliminated to save time, but is necessary currently to observe the operations of the network.

In order for the network to learn, the weights must be adjusted. A well-known mechanism for this process is to compare the outputs with their expected values and compute the error difference, then *back-propagate* the result through the nodes. In our system the error is determined by an Error Computation Node. With the error known, the network can adjust the weights throughout the individual layers to better approximate the result. Error propagation allows the chance of better result on the next cycle of the network. Hence, when the error of the network is computed and this error is within a given allowable error, the network is said to have learned the inputs. Now, whenever the network is presented with the learned inputs, it should have a result the same as the given expected output.

An idealized diagram of a multi-layer back-propagation network is given in Figure 2. Notice the connections signified by the arrows. These connections represent the individual connection weights. The circles represent the nodes, while a vertical row of nodes is a layer. The Input File is a file containing the input data for the network, while the results computed by the network are displayed in the Output Window. There is one new node not explained as of yet. This node, called the Seeder, is responsible for initializing the connection weights to a randomized number. Studies have shown that randomizing the connection weights helps a network arrive at a solution at a faster rate than a uniformly initialized network.

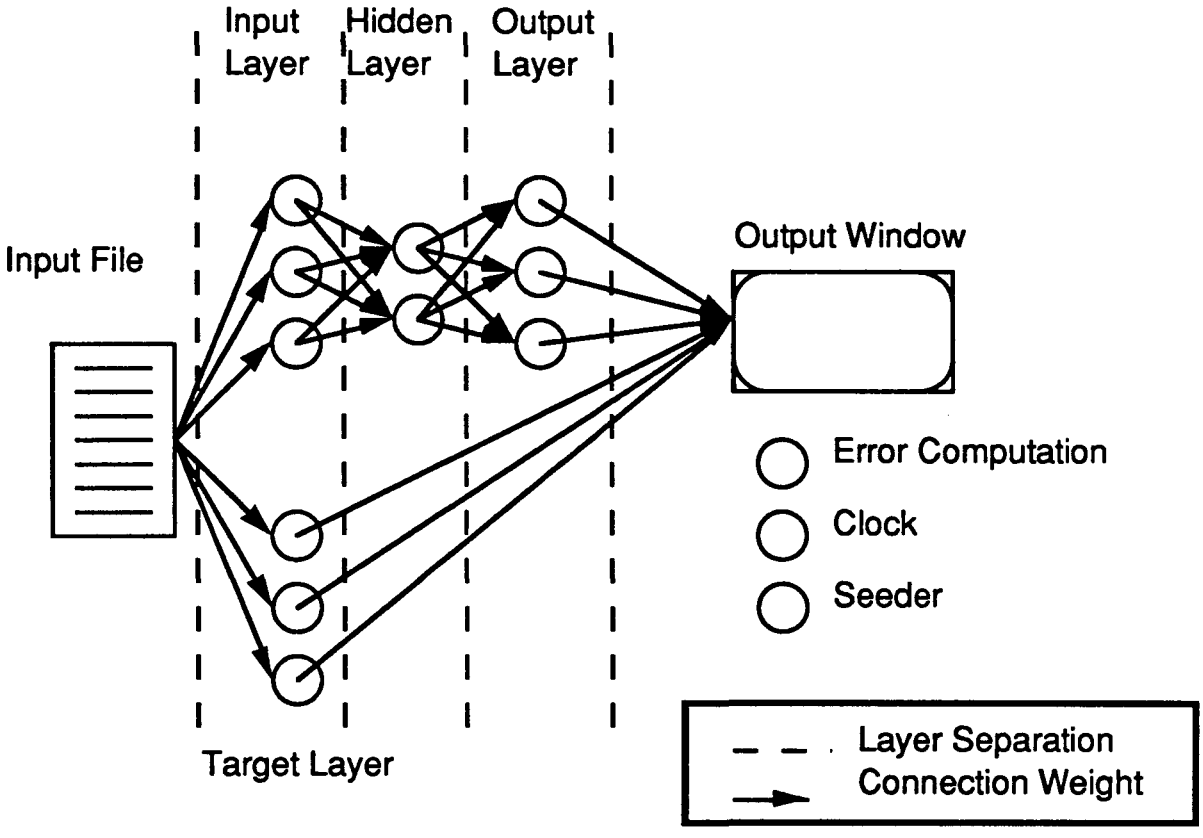

Figure 2. 3 x 2 x 3 Neural Network

Since the same neural network clock cycle is used on several of the networks discussed in the sections to follow, a summary of the individual clock tick is given in Table 1.

Table 1. Clock Tick Summary

On tick 1:	
	All the input values are read from the file, and placed into the first layer. All of the target values are also placed into the target layer nodes.
On tick 2:	
	The values from the input nodes are weighted and placed into the hidden layer nodes, and there they are placed into the logistic function. The result is the output of the hidden layer.
On tick 3:	
	The values from the hidden layer are weighted and placed into the output layer, there they are placed into the logistic function and the output values are computed.
On tick 4:	
	The network is allowed to settle all values. Node values are able to be observed without changes.

On tick 5:

The error is computed and back propagation is performed. If the error is within the given allowable error, the pattern is learned.

Neural System Input/Output

The next logical stage was to properly design the input file and read routines to accept a string of characters as input. This would allow the user to supply a string of characters, i.e., ABCDEFABCDEF, to the network that would be more easily readable than a series of numbers. This is also consistent with the need to process high-level inputs in the form of literal commands and system state labels. In the Cognitron, it is necessary that the input file contain the input values as well as the target values. This is why the input sample above repeats the pattern of inputs. The first set of characters are the actual network input values, while the second set is the target values (the desired learned response). All of these characters need to be converted into numerical input values by the network so that the mathematical computations will be meaningful. The network takes advantage of the ASCII representation of the input and converts the ASCII number to a number from 0 to 1. This process is known as normalization and the LISP function given in Figure 3 performs this normalization of the input.

```
INPUT LAYER 1 NODE 1

(color 1)
(set this_layer 1)
(pattern 1)
(if (eq? global:tick this_layer)
      (begin
            (pattern 5)
            (if (eq? global:read_input 0)
                  (begin
                        (for_every_input in)
                        (set output in)
                        (set output (/ (- output 64) 25)))
                  )
            )
            (set global:out11 output)
      )
)
output
```

Figure 3. Normalization function

Network Configuration

To adequately show how the number of nodes affects the progression of learning, a network with greater than twice the number of nodes was the logical choice in the model development. Proceeding to a network of 7 input nodes, 2 hidden nodes, and 7 output nodes (7 x 2 x 7) began to show exactly how the number of nodes effects the computation time. This would be significant in the decision to proceed to a neural model containing 20 inputs, 5 middle, and 20 output nodes. An example of the 7 x 2 x 7 neural model is shown in Figure 4.

After training the 7 x 2 x 7 network, the results showed that it was able to learn 4 individual inputs in under 1000 iterations. The results also showed that the remaining 3 nodes were taking significantly longer to converge on their expected values. It was approximately 75000 iterations before node three was within the allowable error. Even at 98000 iterations, node 2 and node 1 were still with an error in excess of .023456. To understand how significant this number is, let us examine the determination of the allowable error.

The allowable error is a number that represents the point of where one output is distinguishable from another output. In the case of the neural models discussed in this paper, the output and input values are based on the normalization routine discussed in stage two, above. These values are exactly .037037037037037 apart. That means, in order to distinguish between an 'A' and a 'B', the error has to be less than .037037... 037. This is what is referred to as the allowable error.

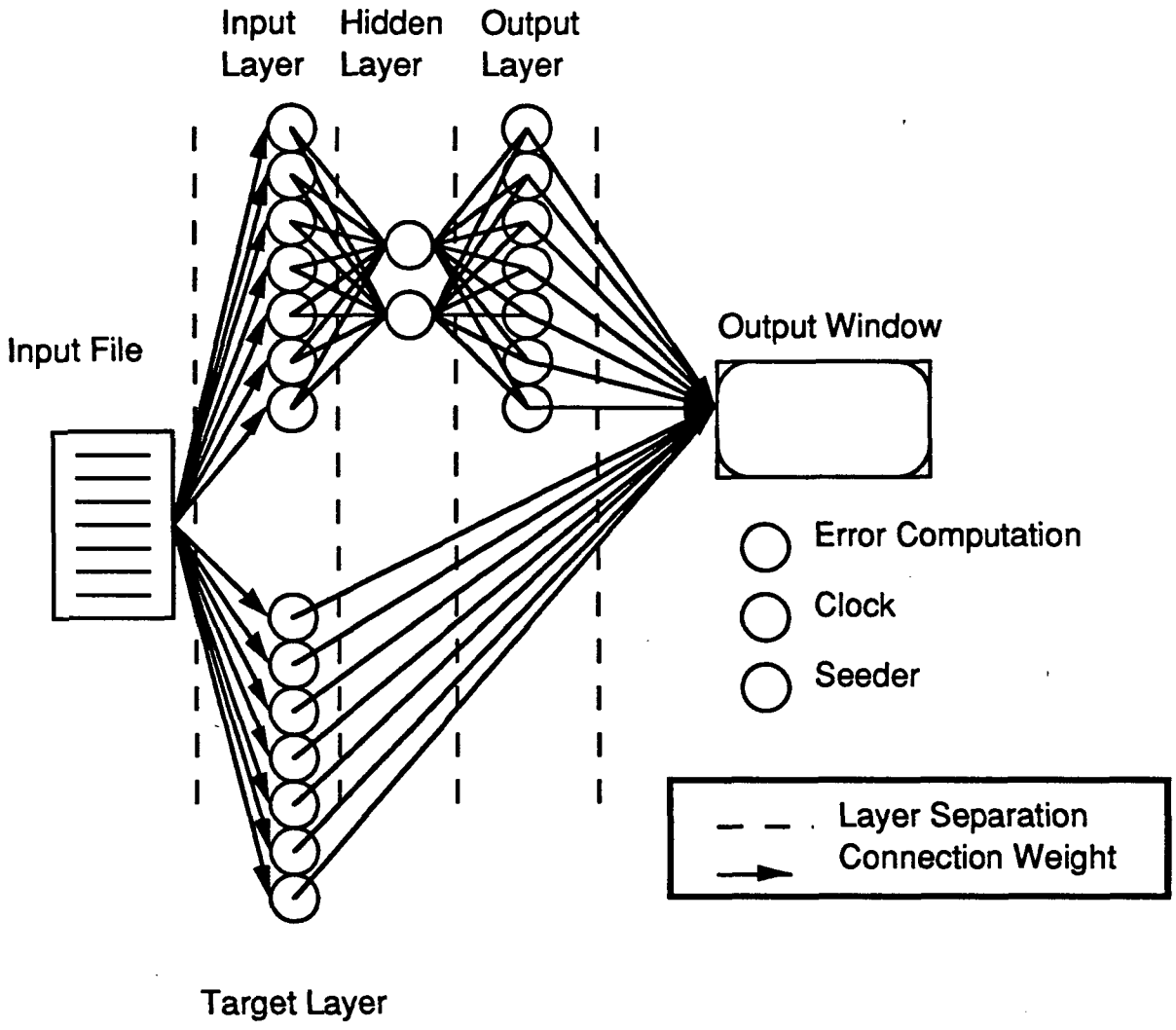

Figure 4. 7 x 2 x 7 Neural Network

Upon close examination, one can see that this network resembles the previous network. However, when adding a single input or output node, you add two extra weights. So, for a 3 x 2 x 3 node network, one would have 12 weights. For a 7 x 2 x 7 network, one would have 28 weights. And for our next stage, a 7 x 4 x 7 neural network we should have 56 weights. The number of weights in the neural network seems to play a significant role in the computation speed of the Cognitron. As the number of weights increases, the speed of the Cognitron Software seems to slow down, almost logarithmically. With this in mind, the next neural model was conceived, a network with 7 inputs, 4 middle nodes, and 7 output nodes. This move was intended to bring down the computation speed of the Cognitron Software by possibly aiding in the convergence of the networks

nodes. After implementation of this model, the network indeed had converged on the targets quicker than the previous models. In fact, some patterns were learned in one-third as many clock cycles as previously noted for a 7 x 2 x 7 neural model.

Although the number of clock cycles decreased by a significant amount, the time that each clock tick took increased by an even greater amount. Therefore, the time it takes for this new neural model to converge on its targets was even greater than the previous model.

A 20 x 5 x 20 neural model was selected for the next stage of development. This model took several days to design, along with twice as many days to debug the code once it was written. The Cognitron has limited debugging capabilities, and this lack of a debugger made the modelling process verification tedious. Since the Cognitron Software uses interpretive LISP, each new segment of code written had to be run in order to be tested. In retrospect, the graphical interface of the Cognitron Software made the schematic design of the network quite simple. The sample of the screen below is provided to show you exactly how the model is represented by the Cognitron.

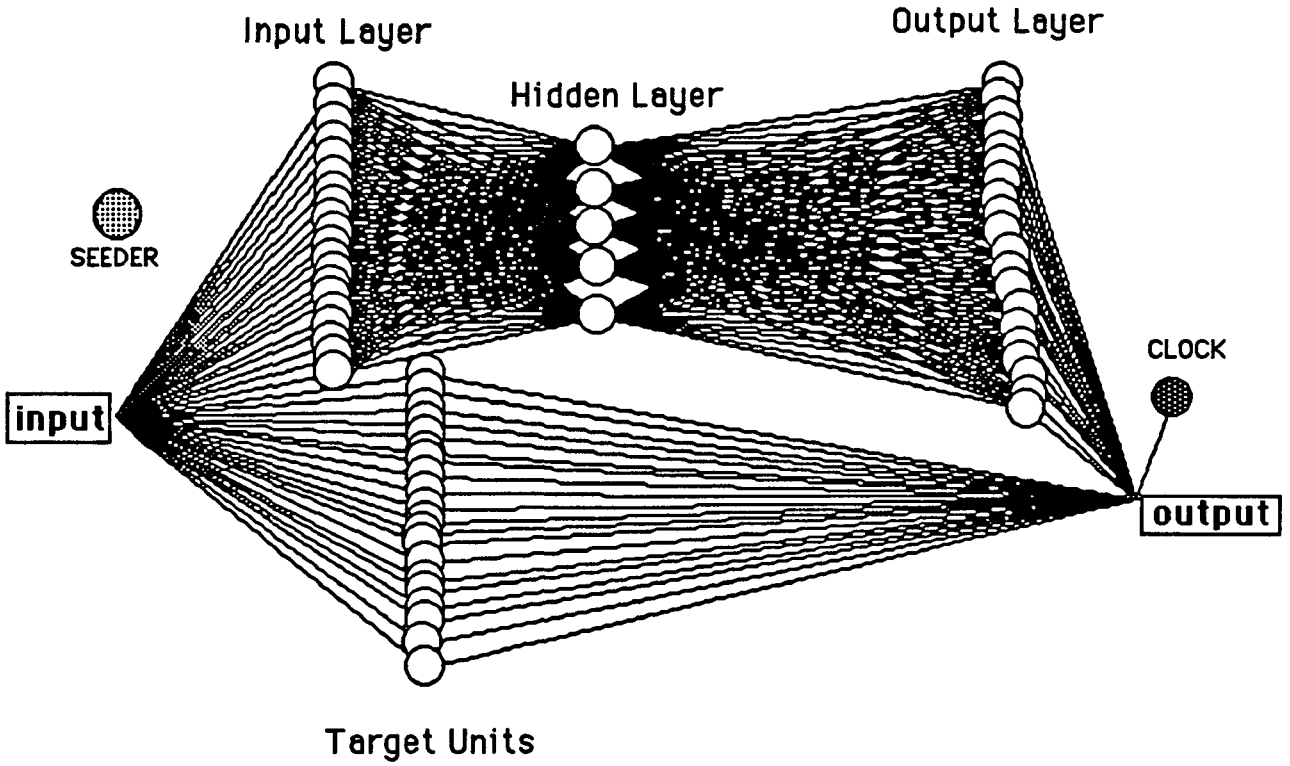

Figure 5. 20 x 5 x 20 Network

Launch System Test Pattern Domain

In order to test the memory-based reasoning capability of the network, we constructed a test domain based on our perceptions of the launch process. For example, the following two strings were presented to the network to be learned:

(1) => 1200 ITERATIONS
NODELCLEARGOODYNOHLD
(2) => 1800 ITERATIONS
SHDELCLEARBDELENOHLD

These strings represent concatenations of launch process state descriptors derived from the table below:

Weather	**Scheduler**
Clear	No Holds
Thuderstorms	Indefinite Hold
Freezing	Scrub Mission
Foggy	
Cloudy	
Operations	**Systems**
No Delays	Good
Short Delay	Bad Reading
Long Delay	Bad Element

We chose four areas to concentrate on, weather, scheduling, operations, and systems. We felt this to be consistent with research that has been performed or is underway that automates these areas in the launch process. The idea is that AI-based programs operating in these areas would make data available to ALOIS for overall evaluation and our model would be conceptually what one might expect from a full-up system, although on a small scale.

This process of using strings of data for memory-based reasoning illustrated a problem in our network design, it was only capable of learning one pattern. If it was taught a second pattern, it would not yield the correct results if the first pattern was resubmitted to the network inputs. Although the patterns were able to be taught to the network, it began to forget any of the nodes that were different than the previous training.

The first pattern was submitted to the network to learn and after1200 cycles, the pattern was confirmed to be learned by the network error computation node. The network was then given the second pattern for learning. After the second pattern was trained and tested, the first pattern was resubmitted, and the network was trained one more time. When the network's error computation node indicated that the learning process was finished for the first pattern,the second pattern was re-submitted. Logically, the network should now recognize both patterns and the results of this test is given in Table 2.

Table 2. Results of Sequential Pattern Training Test

PATTERN 1	PATTERN 2	VALUE	RESULT	CHAR
S	N	.703703	.518519	N
H	O	.296296	.555556	O
D	D	.148184	.148055	D
E	E	.185185	.185187	E
L	L	.444444	.444444	L
C	C	.111111	.111292	C
L	L	.444444	.444444	L
E	E	.185185	.185187	E
A	A	.037037	.030914	A
R	R	.666667	.666667	R
B	G	.074074	.259259	G
D	O	.148148	.555556	O
R	O	.666666	.555556	O
E	D	.185185	.148398	D
D	Y	.148148	.925921	Y
I	N	.333333	.518519	N
D	O	.148148	.555555	O
H	H	.296296	.296296	H
L	L	.444444	.444444	L
D	D	.148148	.148186	D

From the interpretation of the data, it was apparent that the network was only capable of learning one pattern. To test this conclusion, an attempt was made to train with two patterns for four more sessions but, this yielded the same results. Two separate models were now under consideration. The first being the continuation of the Cognitron Software, trying to determine the area in which the present model fails. The second

model was a radically new approach implementing a new form of both hardware and software.

The basic problem with the model was the lack of a threshold node to allow the network to converge on more than one input/learning pattern. This node is a constant term that is added to each and every node in the layer to avoid hysteresis in the error computation across a large sequence of nodes. The addition of this node to an existing Cognitron model is tedious and has a high liklihood of introducing errors into other parts of the model. We elected to test the viability of a threshold node by reproducing the model using a different software system. A program developed at UCF for neural modelling using the objected-oriented C++ language was used. Existing back-propagation code was modified to conform to the standards of our model. This new model included the necessary functions that allowed for the threshold node.

The new model was generated in just a few hours, cutting down on the amount of overhead we had constructing new models on the Cognitron. Also, the processing time that this model needed to complete the training of just one pattern was drastically reduced. This allowed us to train and test the network in minutes where it used to take hours.

A 20 x 5 x 20 neural model was reconstructed using the C++ model and run with the first five patterns. Within 3170 forward propagations, and 2395 backward propagations, we converged on a solution. To confirm the results, we tested the output weights given by the model. The network was able to recognize all 5 patterns without any problem. Eight patterns were then submitted and the network failed to converge after 30,000+ iterations. The network had reached the upper limit on the amount of data it could hold given the existing format.

Before changing anything about the representation of this model, we decided to test the capacity of the five pattern network. If this network did indeed make some generalization about the input patterns, then if a partial pattern (or for that matter a completely incorrect pattern) was submitted, it should try to classify this pattern and return a similar result to the pattern classes learned.

For example, we would expect the following to be true:

Submit: NODELCLEARGOODYNOHLD
Return: NODELCLEARGOODYNOHLD

However, if we submit a partial pattern such as:

Submit: NODELCLEARXXXXXNOHLD

Would it be knowledgeable enough to correctly classify this as:

Return: NODELCLEARGOODYNOHLD

If so, this would indicate the degree of generality that the network has been able to assess from the input data. But, many questions arose. How much of a pattern can be degraded, i.e., the X's in the above pattern, before the pattern is no longer correctly classified? If it was degraded past a certain threshold, how accurate can we expect the output data to be?

A test was devised using X's to indicate unknowns with the following result:

Submit: NODELCLEARGOODYNOHLX
Return: NODELCLEARGOODYNOHLD

Submit: NODELCLEARGOODYNOXXX
Return: NODEL CLEARGOODYNOILD

Submit: NODELXXXXXGOODYXXXXX
Return: NNDDLDMDARHOOEZNNIME

The rate of degradation of the output from the expected output of the pattern is clear. Also, the more of the pattern that is degraded, the worse the response is. The network is getting close. Notice that all of the outputs are within 1 character of the correct value. This can not be attributed to the error level in the training routine because this value was a factor of 1000 below the threshold for the individual characters. The network is associating, but not to the level required.

Restricting the State Space

The model developed so far had such a huge state space that convergence was slow and tedious. A solution was to reduce the state space by reducing the number of the possible classes. Instead of constructing a string with 20 individual outputs (each having a possible 26 different values), we reduced this number to just 5 possible characters on the output end. This allowed us to reduce the number of the inputs to the network to 15. If one looks at the strings, you can see the logical split. Strip off the NOHLD, IDHLD, and SCRUB options and make these the final 5

outputs to the network, while retaining the remaining 15 as inputs. The state space has been significantly reduced and we have a more easily understood result.

With this configuration, we obtained 54 possible input patterns that could be created. But, we really didn't want to teach our newly designed network all of the input patterns, because then there wouldn't be a way to test to see if it had made any generalizations. We selected 9 input pattens that we felt were best suited to train the network with and these 9 patterns would hopefully allow the network to achieve insight to any generalizations possible within the domain. This would allow it to make decisions of totally new data, referencing it's decisions on the past data that it had learned. The 9 patterns that we chose to train the 15 x 5 x 5 network with are given in Table 3.

Table 3. Partitioned Pattern Results

INPUT PATTERN	RESULT
NODELCLEARGOODY	NOHLD
NODELTHSTOGOODY	SCRUB
NODELFREZEGOODY	SCRUB
NODELCLODYGOODY	IDHLD
NODELFOGGYBDELE	IDHLD
SHDELCLEARBDELE	NOHLD
SHDELCLEARBDRED	IDHLD
LNDELRASTOBDELE	SCRUB
LNDELCLODYBDRED	SCRUB

These 9 patterns are the ones that were picked to be the trainers of 54 total patterns. It should be understood that these strings are just one simplified representation of a complex and more difficult decision-making process that goes in the actual launch process.

Our 15x5x5 model was able to learn all 9 of these patterns, but when submitted with the 10th pattern, the system would not converge. This was a perplexing problem that wasn't easily identified at first. After careful scrutiny of this 10th pattern, we found we were teaching the network the same input pattern with two different output patterns, causing the network to reverse it's learning process. Now, upon removal of the 10th pattern, the network learned all of them again. But, when other patterns were

submitted that it did not know (ones that the network was not trained with), the network recognized less than 50% of them.

Modular Approach to Network Training

The next step, logically, would be to find a way to implement a training model that would allow the size of the state space that is required for the input, to be mapped properly to the output. This was our approach all along, but it has finally culminated at this last level.

The final resolution to the problem at hand was to create a multi-layer, multi-level network. Since this is a totally new design, we embarked as quickly as possible. This concept, in theory, would allow us to train sections of the network separately, and individually, with their own set of inputs and expected outputs. Then, after all of these pieces are trained properly, they could be connected together to form a larger network. Then, this larger network could be trained, leaving the trained layers weights alone, producing an even larger model. As you can see, if this theory worked, the time needed to train a network could be cut down drastically, allowing training to occur on several parallel machines. Then the final model could be integrated and tested. This theory is indeed promising. So, we began to design this model.

The first subsection of the network would be for the time dependent section of our inputs. The inputs NODEL, SHDEL, and LNDEL all are time dependent variables that are single dimensional. Therefore, we decided to create a 5 input to 1 output sub-layer network.

Now, we trained this sub-layer network with the following data:

NODEL	0.0
SHDEL	0.2
LNDEL	1.0

Notice that LNDEL is more than twice that of SHDEL. This should eliminate any inconsistencies in the determination of the severity of the input. (LNDEL is longer then SHDEL)

The next sub-layer is the weather sub-layer. This 5 input weather string was converted to an eight node output layer that uses the mean and standard deviations of 4 weather parameters to describe the local weather conditions. These 4 parameters are VISIBILITY, TEMPERATURE, HUMIDITY, and CLOUD COVER. The input values for these four parameters

were compiled from a list of weather conditions on location at the Orlando International Airport during the months of January 1989 to February 1990.

The next sub-layer takes the input strings BDRED, BDELE, GOODY, and converts them into a binary representation of one or the other, with GOODY having the lowest value of the three.

Once these three sub-layers were trained individually, they were spliced together to form one large single network. This network has 3 nodes for it's output. These nodes are significant to the 3 possible states that the network is allowed to have, NOHLD, IDHLD, SCRUB.

Now, since the structure of the code only allows for interlayer full connectivity (meaning a node from the first layer must be connected to every node on the next layer, excluding the threshold node), we had to find a way to simulate a NON-CONNECTED forward path. Noticing that if the weight of this path was set to zero, the output of this path would always be zero, thus eliminating the effectiveness of the path. Now, we could piece together the network in any way we choose. Note that the sub-layers that were already trained to be interconnected to each other are not needed, they should just connect to the next, or 3rd, layer.

During the learning process, we don't wish our weights to change in the already trained sub-layers, so we need some way of turning off the learning process in the lower layers. This is achieved during the training process by assigning a learning rate for each individual layer. If we were to set this learning rate to 0, no modification of the weights is possible.

After this layer was trained, and the output was confirmed, we proceeded to add even one more layer. This layer would help identify the individual output characters by their 5 bit ASCII representations. Now, after training this layer, we will be able to directly convert the output into a meaningful string of data that is exactly the same as the 3 result patterns that we expected out of the original design.

After all of the above sub-layers were trained and connected, we began the process of confirming our hypothesis. We resubmitted the initial 9 patterns to the newly constructed network. After these 9 patterns were trained, we were skeptic about how the outcome would be with fewer than 17% of the total state space submitted to the network for training. We had no idea how much information is required to train a network given so many possibilities of inputs, so our figures were about 16%. Our findings were quite unique. After submission of the 54 patterns to the classifying

network, only 5 inputs were not identified at all. Four of those were identified exactly the same incorrect answer, showing us that the network discovered a generalization that we did not think of; but, this generalization was incorrect in our model because we did not declare that as one of the possible outcomes. The raw data output is as follows:

TEST INPUT PATTERN	OUTPUT RESULT
NODELCLEARBDRED	IDHLD
NODELCLEARGOODY	NOHLD
NODELTHSTOBDELE	SCRUB
NODELTHSTOBDRED	A@@D@
NODELTHSTOGOODY	SCRUB
NODELFREZEBDELE	SCRUB
NODELFREZEBDRED	SCRUB
NODELFREZEGOODY	SCRUB
NODELRASTOBDELE	SCRUB
NODELRASTOBDRED	A@@D@
NODELRASTOGOODY	SCRUB
NODELCLODYBDELE	IDHLD
NODELCLODYBDRED	IDHLD
NODELCLODYGOODY	IDHLD
NODELFOGGYBDELE	IDHLD
NODELFOGGYBDRED	IDHLD
NODELFOGGYGOODY	IDHLD
SHDELCLEARBDELE	NOHLD
SHDELCLEARBDRED	IDHLD
SHDELCLEARGOODY	NOHLD
SHDELTHSTOBDELE	SCRUB
SHDELTHSTOBDRED	A@@D@
SHDELTHSTOGOODY	SCRUB
SHDELFREZEBDELE	SCRUB
SHDELFREZEBDRED	SCRUB
SHDELFREZEGOODY	SCRUB
SHDELRASTOBDELE	SCRUB
SHDELRASTOBDRED	A@@D@
SHDELRASTOGOODY	SCRUB
SHDELCLODYBDELE	IDHLD
SHDELCLODYBDRED	IDHLD
SHDELCLODYGOODY	IDHLD
SHDELFOGGYBDELE	IDHLD
SHDELFOGGYBDRED	IDHLD
SHDELFOGGYGOODY	IDHLD
LNDELCLEARBDELE	NOHLD
LNDELCLEARBDRED	SCRUB
LNDELCLEARGOODY	NOHLD
LNDELTHSTOBDELE	SCRUB
LNDELTHSTOBDRED	SCRUB
LNDELTHSTOGOODY	SCRUB
LNDELFREZEBDELE	SCRUB
LNDELFREZEBDRED	SCRUB

LNDELFREZEGOODY	SCRUB
LNDELRASTOBDELE	SCRUB
LNDELRASTOBDRED	SCRUB
LNDELRASTOGOODY	SCRUB
LNDELCLODYBDELE	SCRUB
LNDELCLODYBDRED	SCRUB
LNDELCLODYGOODY	SCRUB
LNDELFOGGYBDRED	SCRUB
LNDELFOGGYGOODY	SCRUB

The responses that are A@@D@ are particularly unusual in that there are 4 occurrences of the same output pattern. Even a casual observer can see that these particular results all contain a form of RASTO or THSTO and a BDRED string. Two explanations immediately present themselves, first, maybe the network is confused about the severity of a rainstorm vs. a thunderstorm, and secondly, maybe the bad reading has not been represented by enough examples. In both situations, we agreed that the best way to resolve this problem is to teach it another pattern, hopefully one that would correct the inconsistencies of the output.

We chose to train the network with 10 patterns, the original 9 & an additional patten that will allow us to properly identify the 4 incorrectly identify classifications. Upon retraining the network, we resolved 4 of the 5 incorrectly identified patterns, and are currently working on a way to resolve the 5th incorrectly identified pattern.

Conclusion

A multi-layer network with independently trained modules should allow the network to learn more data. To better see this, a graphical representation of this particular model is shown in Figure 6. This model is a hybrid of our original design and is promising from the standpoint of being able to handle larger amounts of data and to learn faster. It is the subject of our current work, which is moving towards a larger network and more complex data domain.

The problems encountered with the Cognitron have been largely overcome with the move to the C++ modelling system. It should be noted that a project to design a Cognitron-like modelling and simulation system is being funded at UCF and this model will be used eventually as the main platform for the ALOIS Memory-Based Reasoning system.

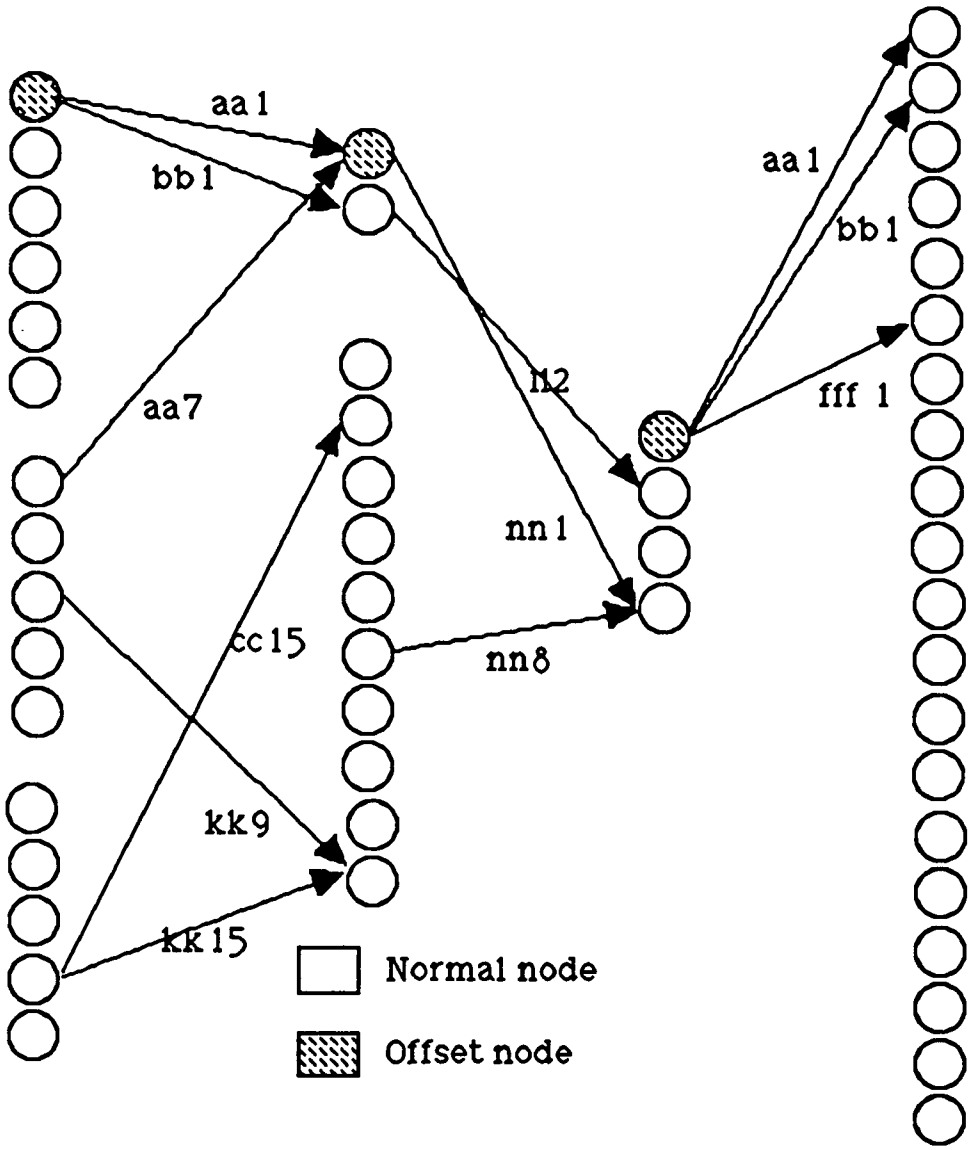

Figure 6. Multi-Layer Network with Independently Trained Modules

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Date of Report:	90/10/05
Title of Report:	Final Technical (Performance) Review Knowledge Acquisition for Artificial Intelligence, Productivity, and Materials Analysis Techniques
Project:	3 - NASA - Knowledge Acquisition
Security Classification:	Unclassified
Name of Issuing Government Activity:	NASA

Natural Language Knowledge Acquisition System
Fernando Gomez and Carlos Segami
Computer Science Department

Planning Phase
NASA Cooperative Agreement
Final Report

During this phase, our research has proceeded in two ways: (a) advancing the state of the art in knowledge acquisition using natural language and (b) designing a conceptual knowledge acquisition prototype for OPERA, an expert system developed at KSC. The appendix contains two publications describing our basic work. In this report, we briefly describe the conceptual prototype for OPERA.

OPERA

The goal of OPERA (Expert System Analyst) is to improve the operations support of the computer network in the space shuttle launch processing system. The checkout, control and monitor subsystem (CCMS) is a distributed computer network, which integrates software, microcode, displays switches and hardware interface devices. OPERA is intended to function as a consultant to the operations staff assigned to each CCMS task. Two basic expert systems form OPERA: the Real Time System Error Manager (RTSEM) and the Problem Impact Analyst (PIA). When an error occurs, RTSEM displays information on this error obtained from a data base of errors. This information, although based on the CCMS message catalog information, contains experiential knowledge which "resides in the head of the human experts, not on texts." The knowledge acquisition bottleneck that the designers of OPERA are presently experiencing is the gathering of this knowledge from the human experts and its transfer to OPERA in a form assimilable by the data structures and algorithms of the expert system. OPERA contains about one hundred thirty of these errors, but the actual number of errors in the computer network is beyond one thousand. Hence, OPERA is short in its knowledge base by a factor of ten.

The Automatic Knowledge Acquisition Interface to OPERA

The aim of our research during this phase has been to design a knowledge acquisition interface by means of which a domain expert without knowledge of OPERA or expert systems will be able to transfer his/her knowledge about the computer network errors to OPERA. There has been a lot of evidence accumulated from many areas of expert systems showing that human experts organize their knowledge in a hierarchy of concepts. This fact became evident to us during our initial interactions with OPERA experts. The hierarchy depicted in Figure 1 was used by the experts all the time when they analyzed errors and determined their causes and corrective steps. The hierarchy in Figure 1 may be hard to understand for anybody unfamiliarized with the computer network. But, for experts in this domain, the hierarchy is as natural as a botanical hierarchy can be for a botanist. The hierarchy is the expert's underlying frame of reference for their domain knowledge.

Accordingly, we have decided that the hierarchy depicted in Figure 1 should be stored in the Interface in order to guide the expert to transfer his/her knowledge to the Interface. Also, an error data base containing basic information about the errors (Figure 2), and a status register decoding table should be part of the Interface to help the expert to decode the bits associated with each error (see Figure 3). This hierarchy has been provided to us by Bruce Hosken of GRUMMAN. We have determined that the domain expert interaction with the Interface should proceed in the

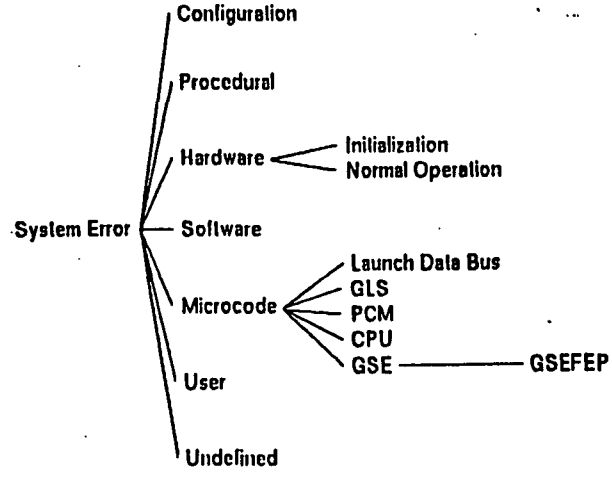

Figure 1. Initial Hierarchy

Sub-System	Error	SS ID	Him Stat	Tr Stat
FEP	132-1	GS3		14CF
FEP	132-2	GS3		34CF
FEP	132-3	GS3		54CF
FEP	133-1	GS3	80	
FEP	133-2	GS3	40	
FEP	133-3	GS3	20	
		•		
		•		
		•		
		•		
FEP	141-1	GS3		
FEP	142-1	GS3		

Figure 2. Data Base of Errors

following way:

(1) The expert is asked to select an error from the pre-stored table of errors.
(2) Then, the expert is asked to classify the error in the hierarchy.
(3) If the expert decides that the hierarchy is not properly organized, he/she may decide to restructure it to meet his/her criteria. The Interface will keep multiple hierarchies each one associated with each expert.
(4) Once the expert has classified the error in the hierarchy, he/she is asked to enter information about that error, as explained in the section below.

We will implement an inheritance mechanism in the hierarchy, so that when the expert is adding knowledge about an error, the Interface automatically shows him/her the facts which are inherited by that error. This helps the expert to refresh his/her knowledge by being *reminded* of pieces of knowledge associated with parent concepts.

The Natural Language Component

The natural language component will play a role in the formation of the hierarchy and during the incorporation of experiential knowledge about concrete errors. The interface will use natural language in the formation and restructuring of the hierarchy by the domain expert. For instance, the expert is asked to select an error, say FEP 1575, and to describe the kind of error. Then, the expert could type something like:

This error is an interface hardware failure caused by a failure of

HIM Status Register Decode Table

8 bits/2 hex digits representing HIM internal errors posted to HIM Status Register
e.g. (for errors FEP 133 & 137)

bit 7: Temp Warning
bit 6: Logic Error
bit 5: Bus Error
bit 4: No Ready
bit 3: Mult Ack
bit 2: No Ack
bit 1: Power Supply Failure
bit 0: Fail Signal

TR Status Register Decode Table

16 bits/4 hex digits representing T/R errors posted to the T/R Internal Status Register
e.g. (for error FEP 132)

bit 15: Parity Error	bit 7: Receiver Enabled
bit 14: Manchester-II Error	bit 6: Transmitter Enabled
bit 13: Overflow Error	bit 5: Self-Test Enabled
bit 12: (spare bit)	bit 4: Command Inhibit
bit 11: Command Inhibit	bit 3: (spare bit)
bit 10: (spare bit)	bit 2: (spare bit)
bit 9: Mode bit 1	bit 1: (spare bit)
bit 8: Mode bit 2	bit 0: (spare bit)

Figure 3. Decoding Table

the memory address register or memory data register.

From this natural language description, the interface could classify the error in the hierarchy. We have built a system to do precisely that, namely the construction of classification hierarchies from natural language descriptions (see [3]). Only a thorough field testing of this feature will tell us if a domain expert will prefer to use natural language to classify the errors, or to use directly the hierarchy as it will be implemented in the Interface, or a combination of both.

The natural language component will be active just after the expert determines how to classify an error in the hierarchy. Once he/she has done that, the interface will ask her/him to enter the probable causes of the error, the operations advisory and the diagnostic advisory. For instance, suppose that the error is FEP (Front End Processor) 133.

Interface: Enter Probable Causes.
Domain Expert:

1. Control card has failed.
2. Master Control Card has failed.
3. Bus Test Card has failed.

4. Internal HIM bus failure.

Interface: Enter Operations Advisory.
Domain Expert:

1. Terminal Error... Inform the user(s) that the HIM is inhibited.
User's programs may be monitoring stale data.
2. A HI '025 GS2A SCAN... If a HI fails, release HIM from support,
and request HIM crew be dispatched

Interface: Enter Diagnostic Advisory
Domain Expert:

Verify if message HIM307 is present. This error message comes from ...

As one can see from the example, the expert will enter the causes and advisory steps in English. The function of the interface will be to parse these sentences and translate them into OPERA data structures.

Plan for WInter 1990

We will start implementing the prototype in the Harris computer in Kyoto Common Lisp. Once we receive the Symbolics machines, we will start transferring the code to the Symbolics. We should have a prototype working by the end of the Winter semester. We will use Symbolics Common Lisp and dynamic windows in the implementation.

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NONDESTRUCTIVE ANALYSIS AND DEVELOPMENT

PRE-PHASE PROJECT
FINAL REPORT

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April 1990

NONDESTRUCTIVE ANALYSIS AND DEVELOPMENT

This final report summarizes the progress and achievements of pre-phase project #4 of the NASA/UCF Cooperative Agreement. The objective of this project was to review NASA's NDE programs at Kennedy Space Center (KSC) and recommend means for enhancing the present testing capabilities through the use of improved or new technologies.

INTRODUCTION

Newly developed methods in nondestructive evaluation (NDE) including laser speckle, holographic interferometry, electronic shearography, acoustic emission, microwave, infrared, computed tomography, and X-ray testing have emerged as practical tools in the field of NDE. These NDE methods promise to play a major role in the continued dominance of the U.S. aerospace industry. The demands for higher efficiency and greater reliability in the design and testing of aerospace components, especially the space Shuttle and its components, have created a need for further refinement of the existing NDE methods and possibly the introduction of new methods.

The practical benefits of nondestructive inspection are obvious. Its use in design and quality control of manufactured parts can provide the assurance of a structure free of defects, and thus increase the certainty that it will perform as intended. NDE can also be beneficial in reducing the frequency of unscheduled maintenance, which usually is more expensive than regularly scheduled maintenance. Often, NDE can be used to inspect questionable parts in-place on equipment, thereby preventing an unscheduled and unnecessary shut down if the part is in fact defect free. Additionally, the NDE

capability is important to the development of advanced materials and structures, which will provide the opportunity for significant improvements to be made in future space transportation systems.

The contemporary period in NDE development is characterized not only by the introduction of sophisticated techniques, but also by the explosive uses of computers for rapid data processing and the combined use of experimental and numerical techniques. These automated inspection systems greatly reduce the time required for inspection, and eliminate the uncertainties typically associated with "operator dependence" of hand operations. It is probably in the development of sophisticated computer pattern recognition and data processing techniques for defect characterization and quantification that the future of NDE lies, rather than in improvements in the existing fundamental techniques (such as holography, acoustics, radiography and magnetics).

The emergence of the science of fracture mechanics, together with the concept of acceptable flaws, have also had a major influence on the philosophy of NDE, particularly in emphasizing the need for accurate, quantitative defect sizing.

In general, the various NDE techniques can be divided into two categories: active and passive. The active techniques are those where something is introduced into or onto the specimen and a response is expected if a defect is present. Magnetics, ultrasonics, and radiography fall into this category. Passive techniques, on the other hand, are those that monitor or observe the item in question during a typical load environment and attempt to determine the presence of a defect through some reaction of the specimen. Holographic interferometry, acoustic emission, noise analysis, leak testing, and visual examination are among this classification. An overview of some of the widely used NDE techniques is presented next.

One of the widely used techniques in nondestructive evaluation is holographic interferometry. Useful characteristics of this technique include simple, non-contact, whole-field visual display, and lack of special requirement for surface preparation of the test object. Holographic interferometry can be used to detect the presence of crack (surface or near surface) in a component, or even to observe its growth in real time. Moreover, the method is used for the detection of debond and delaminations in composite materials and structures. A self-contained holographic camera system is now commercially available. This system is compact, portable, and easy to incorporate in industrial systems designed for specific applications. Other important applications of this technique include flow visualization, vibration analysis, and creation of visual images form microwave holograms.

A second technique that plays a significant role in NDE is computed tomography (CT). It reveals the internal nature of a material. Industrial systems are available as computerized tomographic analyzers. These systems can be used to examine the internal structure and material integrity of a wide variety of aerospace related objects. The examination, nondestructively, is performed by producing a two dimensional picture of a selected slice through an object. The penetrating sources that yield data for reconstructing the slice picture are radioactive cobalt or a high power X-ray tube.

A third technique for nondestructive evaluation is acoustic emission. This technique is used in monitoring structures subject to possible catastrophic failure, e.g., airframes. Another application of the method is locating propagating cracks by detecting stress wave pulses with several transducers and measuring the differences in their arrival times.

A fourth technique for nondestructive evaluation is photoelastic coating. It is a whole-field technique for analyzing and measuring surface strains on a part or structure under applied loads. In this technique, a special plastic coating is bonded to the test

part. Then, as loads are applied to the part, the coating is illuminated with polarized light and observed as a colorful pattern, revealing the overall strain distribution and indicating areas of strain (or stress) concentration. Fringe analysis, which can be conducted by a computerized digital imaging system, yields the necessary quantitative measurements of strains (magnitudes and directions).

A fifth technique used in NDE is infrared scanning. This technique is useful for detecting liquid levels in closed containers, detecting defects in bonded honeycomb materials, and in temperature measurements.

Lastly, electronic shearography is emerging as a powerful tool for NDE. It offers "almost" real-time, full-field capability that presents an image on a video monitor similar to a C-scan. This technique reveals displacement gradient information, and it locates flaws when the test object is subjected to loading.

Other available NDE techniques include: ultrasonic, microwave, magnetic, eddy current, and CCTV visual testing. The following table summarizes the common NDE methods.

Common NDE Methods

Method	Applications	Advantages	Limitations
Liquid Penetrant	Surface cracks, porosity, laminations, etc. that are open to surface.	Inexpensive, portable, independent of magnetic and electrical properties of material.	Defects must be open to surface. Porous and rough surfaces excluded. Penetrant must wet surface.
Magnetic Particle	Cracks, inclusions, and other discontinuities on or near surface of ferromagnetic materials.	Low cost. Suitable for large, immovable objects.	Sensitivity strongly affected by depth of flaw and presence of coatings. Tests in several directions often required.
Ultrasonic	Cracks, laminations, bonding faults, etc.	Detects flaws deep in part. Inspect from one side. Immediate results.	Flaws parallel to sound source are undetectable. Reference stardards required.
Radiography	Castings and welds with thick flaws.	Permanent record. Detects flaws at any depth.	Radiation hazards. Surrounding areas must be shielded from radiation. Thickness limited by strength of radiation source. High equipment and operating costs. Cracks perpendicular to radiation beam may be undetectable.
Neutron Radiography	Inspection of adhesive-bonded metals. Boron-fiber-reinforced metal matrix composites.	Detects lightweight substances within metals.	Requires nuclear reactor or neutron accelerator on the site.
Microwave	Thickness gaging. Chemical composition and moisture content of plastics. Discontinuities.	Well suited for plastics and ceramics. Multiple flaws in beam path can be detected.	Resolution limited to several mm. Poor penetration in conductors.

Eddy Current	Conductive materials with constant cross section; especially pipe inspection. Detects variation in metal type and microstructure as well as flaws.	Very sensitive. Fast enough for continuous on-line inspection. Metal need not be ferromagnetic.	Often too sensitive to unimportant parameters or minor dimensional fluctuations.
Optical Holography	Debonding in honeycomb, composites, and other bonded structures. Hollow turbine blades. Stress corrosion cracking in metals.	Materials need not possess special properties (conductivity, ferromagnetism, etc.). Very sensitive.	Parts are stressed during test. Tedious positioning required.
Acoustical Holography	Continuous inspection of steel sheet. Porosity and lack of bonding in welds.	Immediate results. Detects flaws at any depth.	Limited resolution. Inspection area larger than transducer. Parts must be immersed.
Acoustic Emission	Pressure vessels. Aircraft structures. Welds. Stress corrosion cracking.	Tests parts during structural loading. Pressurized-vessel flaws are detected before failure. All loaded areas are tested, regardless of sensor location.	Plastic deformation during test is irreversible; test is therefore unrepeatable.
Infrared	Debonding in laminated materials.	Low cost. Results easy to interpret. Ideal for checking bond to honeycomb.	Part must be heated.
Electronic Shearography	Debonds, voids, porosity, moisture.	Very sensitive. No vibration isolation required. Field portable.	Parts are stressed during test.
Computed Tomography	Internal flaws.	3-D information.	Very expensive, lab testing.
Photoelastic Coating	Strain/stress measurement.	Complete whole field surface information.	Requires preparation for the coating.

ACHIEVEMENTS

The work was divided into THREE main tasks. A summary of the work performed on each of them follows.

TASK I. Conduct KSC Needs Survey for NDE Technology

The principal investigator (P.I.) spent a major portion of Summer 1989 reviewing the existing NDE program at KSC, which is primarily administered and operated by EG&G Florida. The P.I. Interacted with the NDE lab manager, engineers, and technicians, as well as other users of this technology at KSC. The present NDE capabilities have been identified to include the following:

- Computed Tomography
    - * CT refers to cross-sectional images of an object from transmission data collected by radioactive illumination of the object from several different directions. It is used to examine the internal structure and material integrity of objects
    - * KSC acquires one to the most advanced CT systems. This system could be further improved through upgrading its computer
- Radiography (portable and stationary equipment)
    - * Detects voids, porosity, inclusions, and cracks
- Ultrasonic (A scan)
    - * Detects cracks, voids, porosity, and delaminations
    - * Used for thickness gaging
- Infrared scanning
    - * Detects disbands
    - * Determines liquid levels in closed containers
    - * Locates hot or cold spots in thermally active assemblies
    - * Used for temperature measurement
- Eddy Current
    - * Detects crack and seams

    * Used for thickness gaging

- Liquid Penetrants

    * Detects cracks, gouges, porosity, laps, and seams

- Magnetic Particles

    * Detects cracks, seams, laps, voids, porosity, and inclusions

- Leak Detection

    * Detects leaks in closed systems

- CCTV Inspection

    * Used for visual inspection

- Others

The following table and bar chart are the results of this survey.

TASK II. Investigate NDE Technologies That Would Enhance Mission Support at KSC

Means for improving the present NDE capabilities and introducing new technologies which would enhance mission support at KSC were investigated. This was accomplished by reviewing the literature of NDE methods and initiating a NDE users needs survey at KSC (results are displayed in the arrow chart). the following areas were identified as viable candidates for further improvements or addition to the existing NDE capabilities at KSC.

a) *Improved Capability*

- Computed Tomography

    * computer upgrade (from SMS)

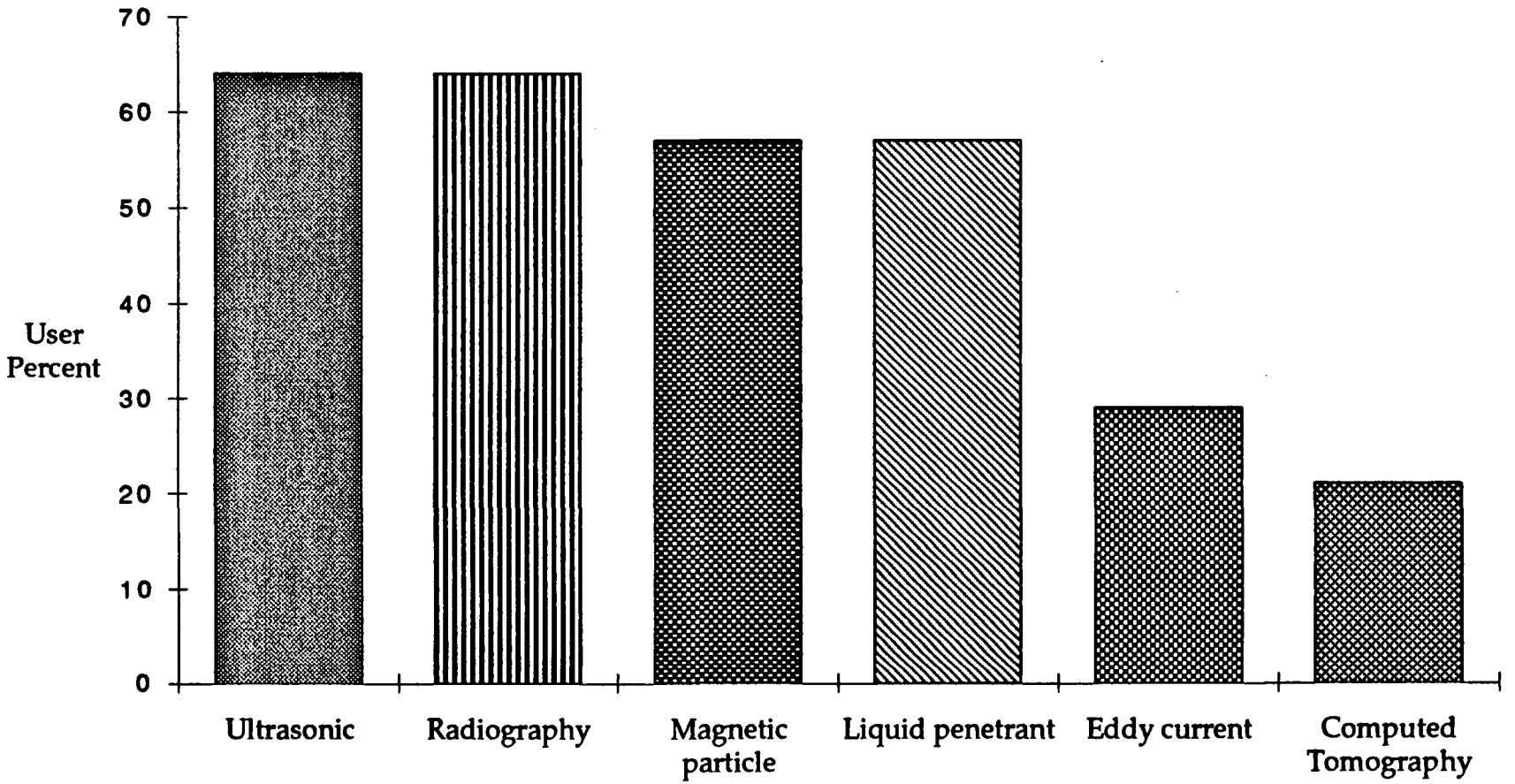
- X-ray Radiography

NDE NEEDS SURVEY
AT KSC

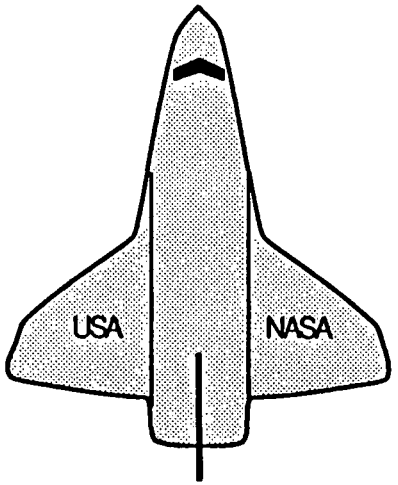
CONTACT PERSON	NDE TECHNIQUES PRESENTLY USED	NEEDED NDE CAPABILITY	FUTURE NEEDS FOR NEW/IMPROVED NDE CAPABILITY
B. Denaburg NASA KSC Malfunction Lab	Eddy Current, Mag. Part., A and C Ultrasonic, X-Ray, CT	Testing and Evaluation of irregular-shaped objects	
S. Murray NASA KSC Material Science Lab	Dye Penetrants, Mag. Part., CT, Radiography, Ultrasonic	Simultaneous CT scanning and monitoring of objects.	Advanced computer system capable of both scanning and monitoring. Real-time and computerized Radiography
B. Speece NASA KSC Material Science Lab	Ultrasonic, Lasers, Holography		Shearography
C. Springfield NASA KSC Materials Science Lab	Flouroscope, X-Ray, mostly uses destructive methods	Acoustic Emission Monitoring	
S. Higginbotham NASA KSC Materials Science Lab	Infrared Scanning		Multispectra Scanning
D. Noeske Lockheed Ultrasonic & Eddy Current	Radiography, Eddy Current, Fiberoptic Borescope		Shearography
G. Jensen Lockheed Radiography	Magnaflux, Infrared Scanning, Ultrasonic, Dye Penetrants, X-Ray, Eddy Current	Fixturing of tube head and receiver, testing and evaluation of irregular-shaped objects.	Real-time Radiography with micro-focus
Blackard Lockheed Pressure Vessels		Improved and faster means to get test data from EG&G NDE Lab	

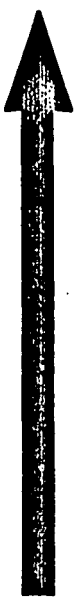
CONTACT PERSON	NDE TECHNIQUES PRESENTLY USED	NEEDED NDE CAPABILITY	FUTURE NEEDS FOR NEW/IMPROVED NDE CAPABILITY
D. Casserda Lockheed Girder Inspection	Ultrasonic, Mag. Part, Dye Penetrants	Testing tubular structures for corrosion. Measuring compactness of castings and forgings of complex shapes. A faster method to inspect launch structures for internal defects.	
R. Smith Lockheed Weld/Machine Shop	X-Ray, Dye Penetrants, Mass Spec., Cold Shock, Ultrasonic	Improved and faster means to get test data from EG&G NDE Lab.	
S. Bohannon Lockheed Cranes	Magnaflux, Dye Penetrants		
D. Sharp General Physics Pressure Vessels	Radiography, Ultrasonic, Mag. Part, Accoustic Emission, Computed Tomography, Fiber-optic Borescope, Replication, Dye Penetrants, Digital Thickness Check		NDT of composites. Methods for identifying unknown materials in the field. Real-time imaging.
J. Yeh USBI Quality Engineering	X-Ray, A,B,C Ultrasonic Scanning, Dye Penetrants, Mag. Part., Eddy Current, Portable Hardness		Infrared, Process Automation, Image Processing, Artificial Intelligence
C. Moore EG&G Pressure Vessels	X-Ray, Ultrasonic, Dye Penetrants, Mag. Part.	Means for detecting corrosion of outside surface of shells that are covered by external bands. Testing of welds in double shells.	

NDE Techniques Presently Used at KSC

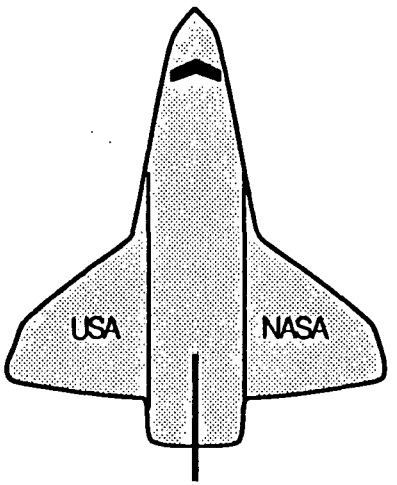


KSC's Need for New/Improved NDE Capability





Real-time Radiography



Shearography

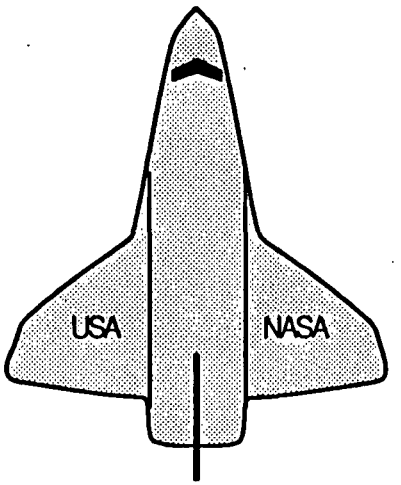


Image Processing

    * real-time system (Lixi Mobilix, which is field portable)

- Infrared

    * Inframetric model 600 infrared camera system
    * computer image analysis

- Ultrasonic (C-scan)

    * immersion tank
    * 3-D computer image analysis
    * computerized scanning

b) New Capability

- Electronic Shearography

    * for possible use in tile bond verification

- Digital Image Analysis

    * DuPont NDT Scan IV Workstation was suggested
    * it will be used in radiographic and infrared applications

- Photoelastic Coating

    * this is a whole-field technique for measuring strains/stresses on a part or structure under applied loads
    * possible use in crane hook testing
    * model 040 direct digital display reflection polariscope was suggested

- Acoustic emission

    * monitors structures under operating loads to provide an early warning of possible failure (potential application is pipelines monitoring)
    * PAC model Locan-AT was suggested

- Electric Resistance Strain Gage System

- Holographic and Laser Speckle Interferometry

    * Newport's fully automatic holographic system (model HC-300/500) is currently available at UCF. It was used in the vibration testing of TPS tiles.

TASK III. Develop Matrices for Ongoing NDE Studies

Recognizing that NDE is a rapidly developing field, it is anticipated that major changes in it would occur in the near future, particularly in the areas of instrumentation, computers, and the development of new techniques. Thus, an ongoing NDE studies were closely examined. Emphasis were placed on those research results that would have potential application, with no or slight modification, to KSC NDE programs.

NDE literature from NASA and other research centers was continuously monitored. Samples of these sources are:

- Applied Science & Technology Index (quarterly)
- The Engineering Index (monthly)
- State University System (ROM)
- NASA Langley Research Center
- Nondestructive Testing Information Analysis Center, Southwest Research Institute (several state-of-the-art survey monographs have been ordered to KSC & UCF libraries)

In addition to the above three tasks, the P.I. has enhanced KSC technical expertise in the area of NDE by reviewing projects sponsored by PT-AST. The following are examples of these projects.

- EG&G Idaho tile bond verification
- Lockheed/VPI tile bond verification

- Lockheed step and gap laser gun

Moreover, digital image analysis of radiographic films has been tried at UCF on the PC Vision Frame Graber system. Also, UCF's Eikonixscan 78/99 high resolution image digitizing system (2048 * 2048 pixels) is being considered for such analysis.

CONTINUATION/FUTURE WORK

A three-year proposal was developed and approved for funding by NASA. the previous three tasks will continue, however, emphasis will be on developing a reliable bond verification technique for the TPS tiles of the space shuttle orbiter. We have already begun the efforts toward modeling the tiles and finding their vibration response using the finite element method. Further, an investigation of the emerging technologies in non-contact modal analysis is underway.

In other NDE areas, collaboration between the P.I. And UCF faculty and NASA researchers has begun. Particular areas are:

- Real-time holographic monitoring of stress corrosion cracking of structures in collaboration with Dr. Desai and NASA-KSC Materials Science Lab.
- Vibration and strain measurements of the launch pad in collaboration with Dr. Gary Lin and Mr. Tim Yang of NASA-KSC.

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NASA / KSC and UCF

MATERIALS PERFORMANCE AND CORROSION PROTECTION

PROGRESS REPORT
SUBMITTED ON
APRIL 30, 1990

P.I. Dr. VIMAL H. DESAI
Mr. KIRK SCAMMON
Mr. EDWARD PRINCIPE

PURPOSE

The purpose of this document is to provide an accounting of the investigation conducted by the University of Central Florida Materials Research Laboratory and NASA\KSC in the areas of stress corrosion cracking and electrochemistry of protective coatings.

BACKGROUND

Corrosion continues to be one of the major problems encountered in everyday operations at the Kennedy Space Center. The effects of corrosion range from unsightly blemishes to catastrophic failures of structural members. Of all the forms of corrosion, two of the more commonly encountered are stress corrosion cracking and general corrosion.

Stress corrosion cracking (SCC) is the brittle failure of a normally ductile alloy exposed to a corrosive environment. Failures associated with SCC usually occur at stresses below that for which the alloy was rated. Stress corrosion cracks propagate by two modes, transgranular (TGSCC), intergranular (IGSCC) and also mixed mode which is a combination of the two previous modes. Transgranular cracks travel through the grains of metal, while intergranular cracks follow the grain boundaries. SCC is avoided by selecting a metal that does not experience SCC in the environment of interest.

General corrosion is the uniform loss of material from all exposed surfaces of a metal. General attack is combated by two methods. The first method is to coat the exposed surfaces of the metal with a material that resists corrosion. The second method is by coupling a metal to one that corrodes preferentially to the one that is to be protected or by impressed cathodic current.

DESCRIPTION OF THE PROJECT

INTRODUCTION

This investigation has been divided into three tasks; 1) SCC susceptibility studies, 2) Mechanistic aspects of SCC and 3) Electrochemical studies of protective coatings. Tasks 1 and 2 are conducted at UCF while task 3 is currently being conducted at KSC.

The SCC susceptibility of a number of alloys is determined by slow strain rate technique so that the alloys may be ranked as to their SCC resistance. Slow strain rate technique was chosen because it is a relatively quick method when compared with other techniques such as fracture mechanics approach or U-bend tests.

Two techniques were chosen to probe the mechanisms of SCC, they are Load Pulsing and Laser Interferometry. Load pulsing provides a method of accurately determining the velocity of crack propagation and the activation energy required to initiate SCC. Laser interferometry allows for real time observation of the cracking process, thereby revealing fundamental information about SCC phenomena such as whether or not SCC is a discontinuous or continuous process and crack jump distance per event.

The protective coatings are studied by the following techniques; Exposure, AC Impedance and Small Amplitude Cyclic Voltometry (SACV). Exposure testing allows coatings to be rated as to their effectiveness and durability. AC Impedance and SACV provide an electrochemical method of quantifying protective efficiency of coatings over a period of time.

SCC SUSCEPTIBILITY STUDIES BY SLOW STRAIN RATE TESTING

Slow strain rate testing consists of pulling tensile specimens to failure in both air and the environment of interest. After tests are run, the mechanical properties of the specimens pulled in solution are compared to those of the specimens pulled in air. SCC is indicated if there is a decrease in the time to failure, maximum stress, strain at maximum stress, maximum strain or reduction in area.If the mechanical properties data indicates SCC, the specimens are examined by Scanning Electron Microscopy (SEM) to determine if SCC occurred and to quantify the amount.

The alloys studied to date are as follows:

* 303 annealed
* 304L annealed
* 316L annealed
* 17-4PH annealed
* 17-4PH H1150
* 17-4PH H1025
* 17-4PH H900
* Inconel 718 annealed.

The environment chosen for this testing is one that represents the conditions at the launch facilities at KSC. Natural seawater was collected in the vicinity of launch complex 39, this water was then filtered and adjusted to pH=1 with hydrochloric acid.

Control specimens were pulled to failure in air at room temperature at a strain rate of 3.76x10-6 per second. Environment testing consisted of pulling the specimens to failure in aerated test solution at room temperature at 3.76x10-6 per second. Some environment tests were conducted at different strain rates to determine the effect of strain rate on SCC susceptibility.

Table #1 summarizes The results of the mechanical properties data from SSR testing. The same results are shown as bar charts in figures 1 through 10. Table #2 shows the actual data for each alloy.The extent of stress corrosion cracking as determined by SEM analysis was the main criterion in determining susceptibility as this was found to be independent of surface finnish.

The SSR data indicates that Inconel 718 shows no susceptibility. The following alloys showed minimal susceptibility: 17-4PH annealed, 17-4PH H1150, 304L and 316L. The following alloys showed considerable susceptibility: 303, 17-4PH H900 and 17-4PH H1025. A comparison of the hardness and susceptibility of the alloys tested indicates that as the hardness increases so does the susceptibility.

Data from SSR tests conducted at different strain rates show that strain rate effects susceptibility as shown in figures 11 through 16. In figure 16, the fracture area ratio is defined as the ratio of SCC area to the total fracture area. With decreasing

ALLOY	TIME TO FAILURE	MAXIMUM STRESS	STRAIN AT MAXSTRESS	MAXIMUM STRAIN	REDUCTION IN AREA
303 ANNEALED	-71%	-34%	-75%	-68%	-75%
304L ANNEALED	NO CHANGE	NO CHANGE	-4%	-6%	-16%
316L ANNEALED	NO CHANGE	NO CHANGE	-12%	-12%	NO CHANGE
INCONEL 718	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE
17-4PH ANNEALED	-10%	NO CHANGE	NO CHANGE	NO CHANGE	-17%
17-4PH H1150	-5%	NO CHANGE	-9%	-9%	-8%
17-4PH H1025	-42%	NO CHANGE	-40%	-60%	-67%
17-4PH H900	-30%	NO CHANGE	NO CHANGE	-40%	-27%

TABLE #1 DIFFERENCE BETWEEN AIR AND SOLUTION TESTS

TEST	ALLOY	TIME TO FAILURE	MAX STRESS	STRAIN @ MAX Stress	MAX STRAIN	Reduction IN AREA
AIR AVG	303 A	52.5	93.9	69.5	67.5	28.9
SOLN AVG	303 A	15.3	62.1	12.5	20.5	5.7
SOLN #1	303 A	13.5	60.3	11.8	17	5.6
SOLN #2	303 A	14.6	59.7	12.4	19.4	6.6
SOLN #3	303 A	17.8	66.2	13.2	25	5
AIR AVG	304L A	87.7	92.3	110	116	66.1
SOLN AVG	304L A	85	95.5	105.6	109.6	56.4
SOLN #1	304L A	88	93.6	109.6	112.6	59.8
SOLN #2	304L A	87	97.6	105.8	111.8	61.3
SOLN #3	304L A	80	95.2	101.4	104.5	48.2
AIR AVG	316L A	77	85.8	111.2	114.6	55.9
SOLN AVG	316L A	77.7	82	98.7	100.7	54.5
SOLN #1	316L A	77	82.2	97.1	98.6	56.2
SOLN #2	316L A	80.6	79.8	103	106	56
SOLN #3	316L A	75.5	84.1	96.1	97.6	51.4
AIR AVG	17-4 H900	18.2	204.9	11.5	20.5	37
SOLN AVG	17-4 H900	12.7	202.6	11.2	11.7	11
SOLN #1	17-4 H900	13.2	196	11.6	12.5	10.5
SOLN #2	17-4 H900	11.8	205.7	11	11.5	9.9
SOLN #3	17-4 H900	13.2	206	11	11	12.6
AIR AVG	I718 ANLD	53.1	134.32	63.25	66.5	50.95
SOLN AVG	I718 ANLD	52.8	137.2	62	65.17	48.66
SOLN #1	I718 ANLD	52.2	135.5	61.5	64.5	49.9
S0LN #2	I718 ANLD	52.8	135.8	62	65	50.5
SOLN #3	I718 ANLD	53.4	140.2	62.5	66	45.6
AIR AVG	17-4 AN	14.5	166.1	9.55	16.25	35.17
SOLN AVG	17-4 AN	13.03	172.4	9.77	14.63	29.73
SOLN #1	17-4 AN	12.8	173	9.8	14.4	28.2
SOLN #2	17-4 AN	13.2	169.7	10	15	33.87
SOLN #3	17-4 AN	13.1	174.4	9.5	14.5	27.2
AIR AVG	17-4H1025	18	169.15	20.4	14	31.6
SOLN #1	17-4H1025	6.8	176.8	12.5	13	13.82
SOLN #2	17-4H1025	9.6	170.4	8.5	7.5	8.07
SOLN #3	17-4H1025	32.4	169.7	6.6	6	11.3
AIR AVG	17-4H1150	17.5	160	22	16	36.3
SOLN #1	17-4H1150	16.5	166.6	14.5	20.5	34.7
SOLN #2	17-4H1150	11	155.8	15	19	30.8
SOLN #3	17-4H1150	73.5	155.6	14.8	22	39

TABLE II : Data for the alloys tested.

TIME TO FAILURE

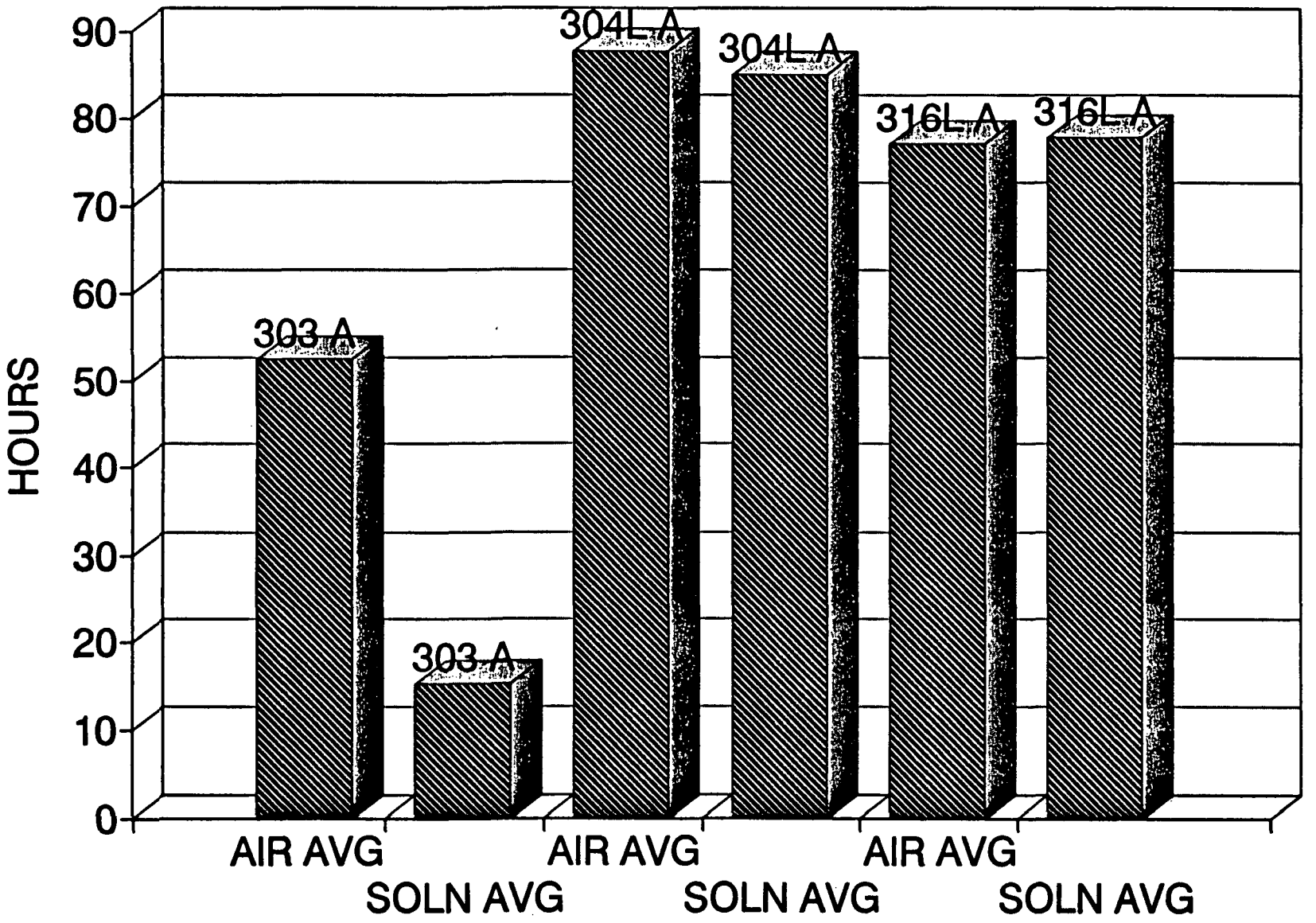

FIGURE 1.

TIME TO FAILURE

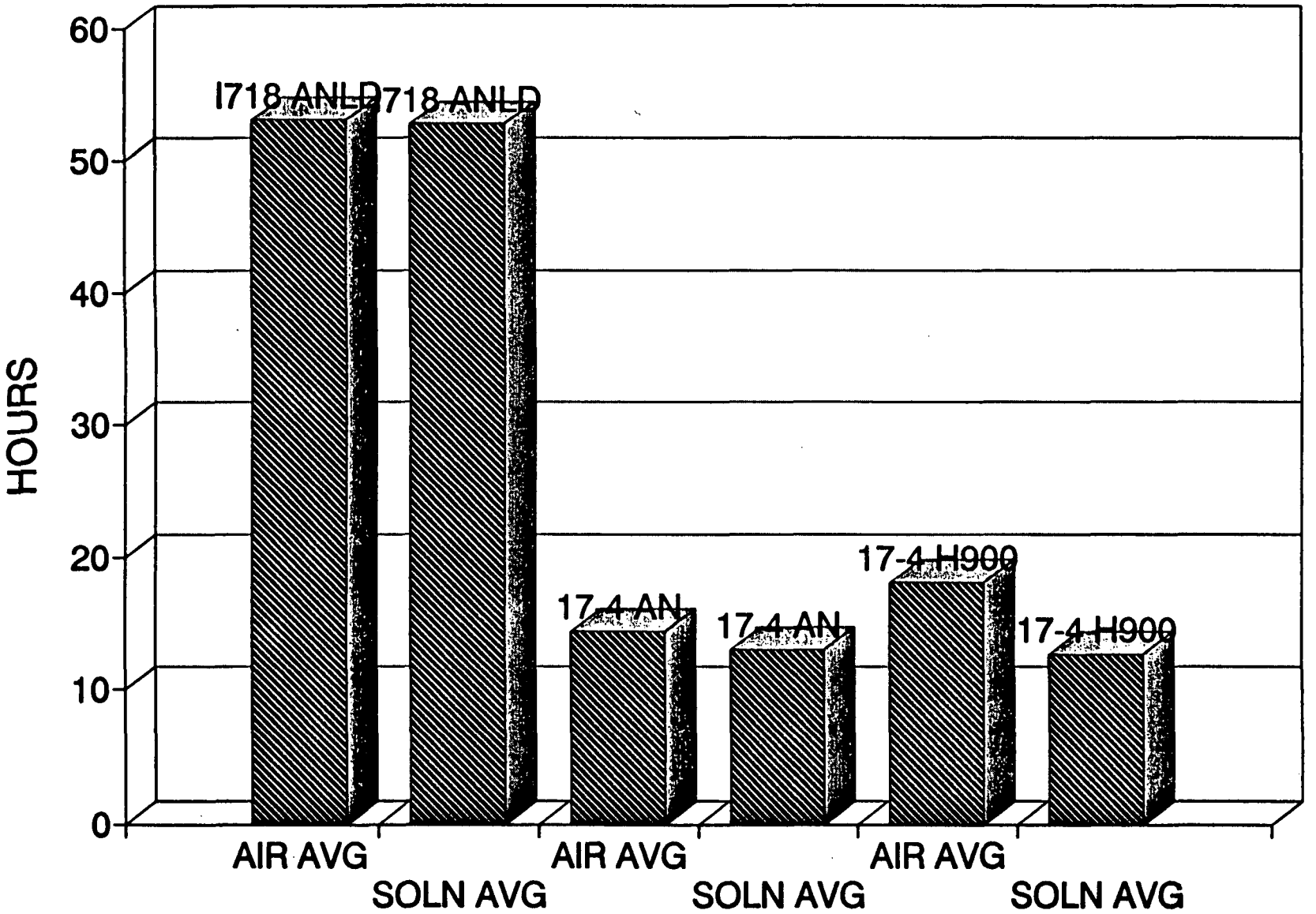

FIGURE 2.

MAXIMUM STRESS

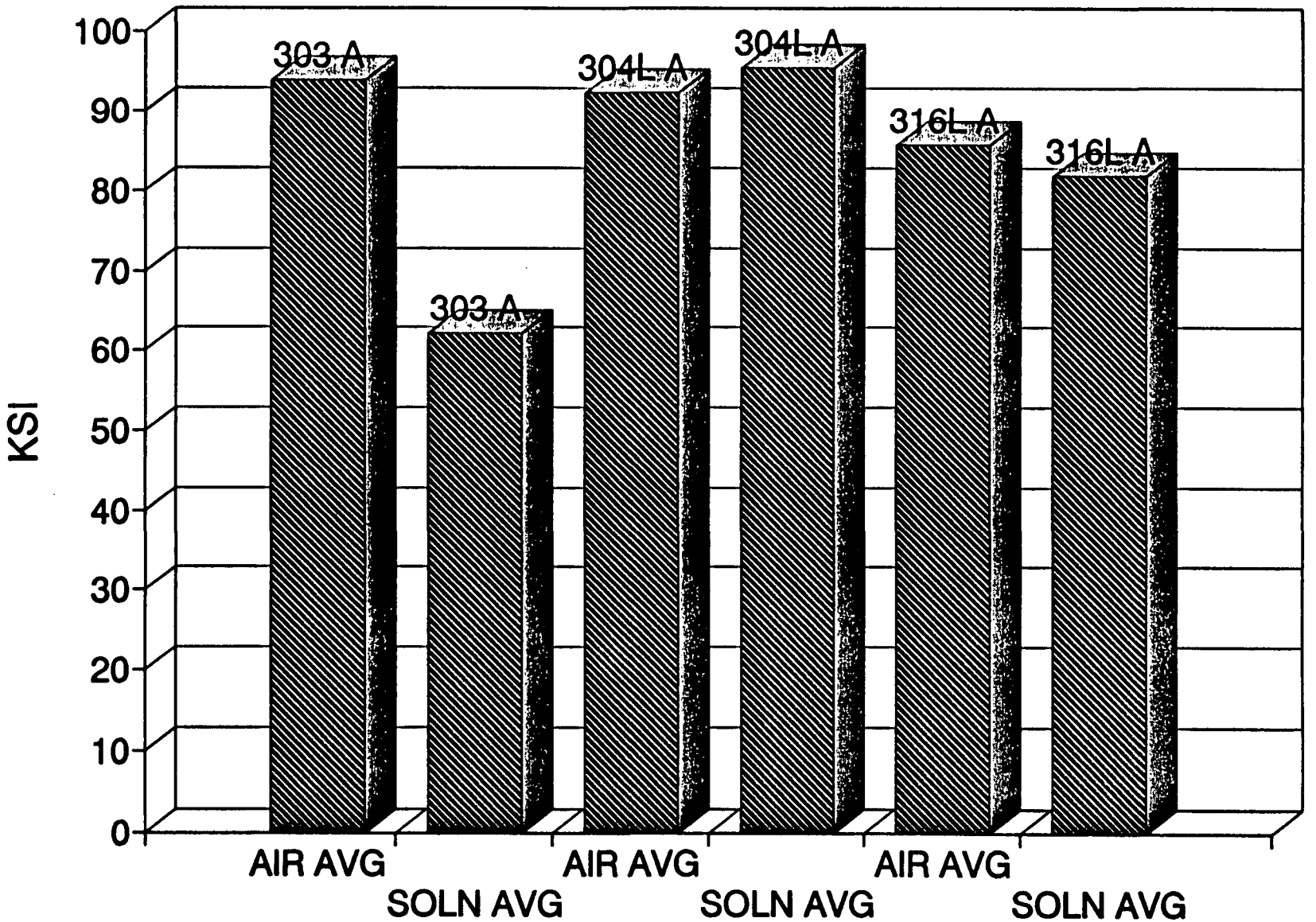

FIGURE 3.

MAXIMUM STRESS

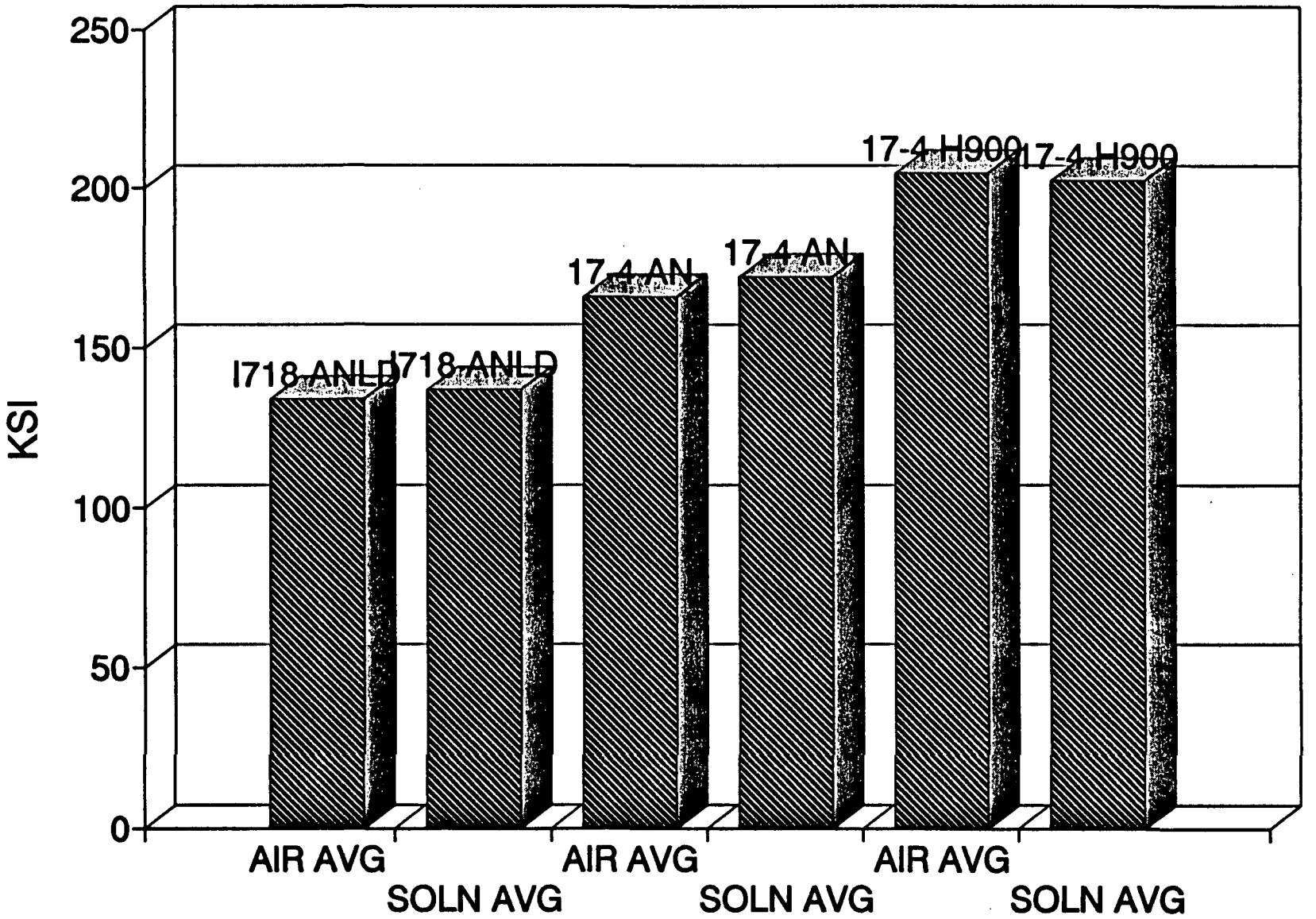

FIGURE 4.

MAXIMUM STRAIN

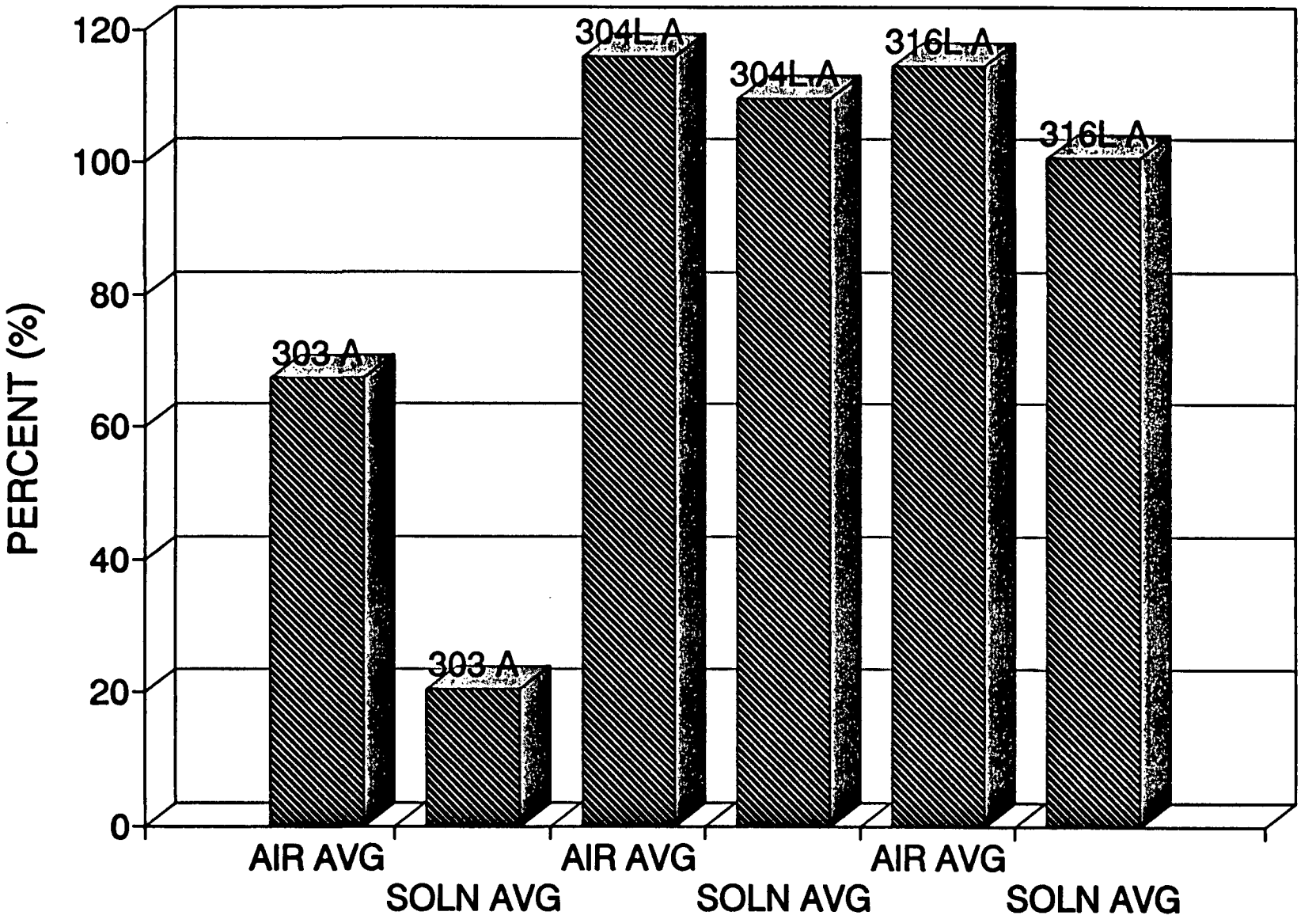

FIGURE 5.

MAXIMUM STRAIN

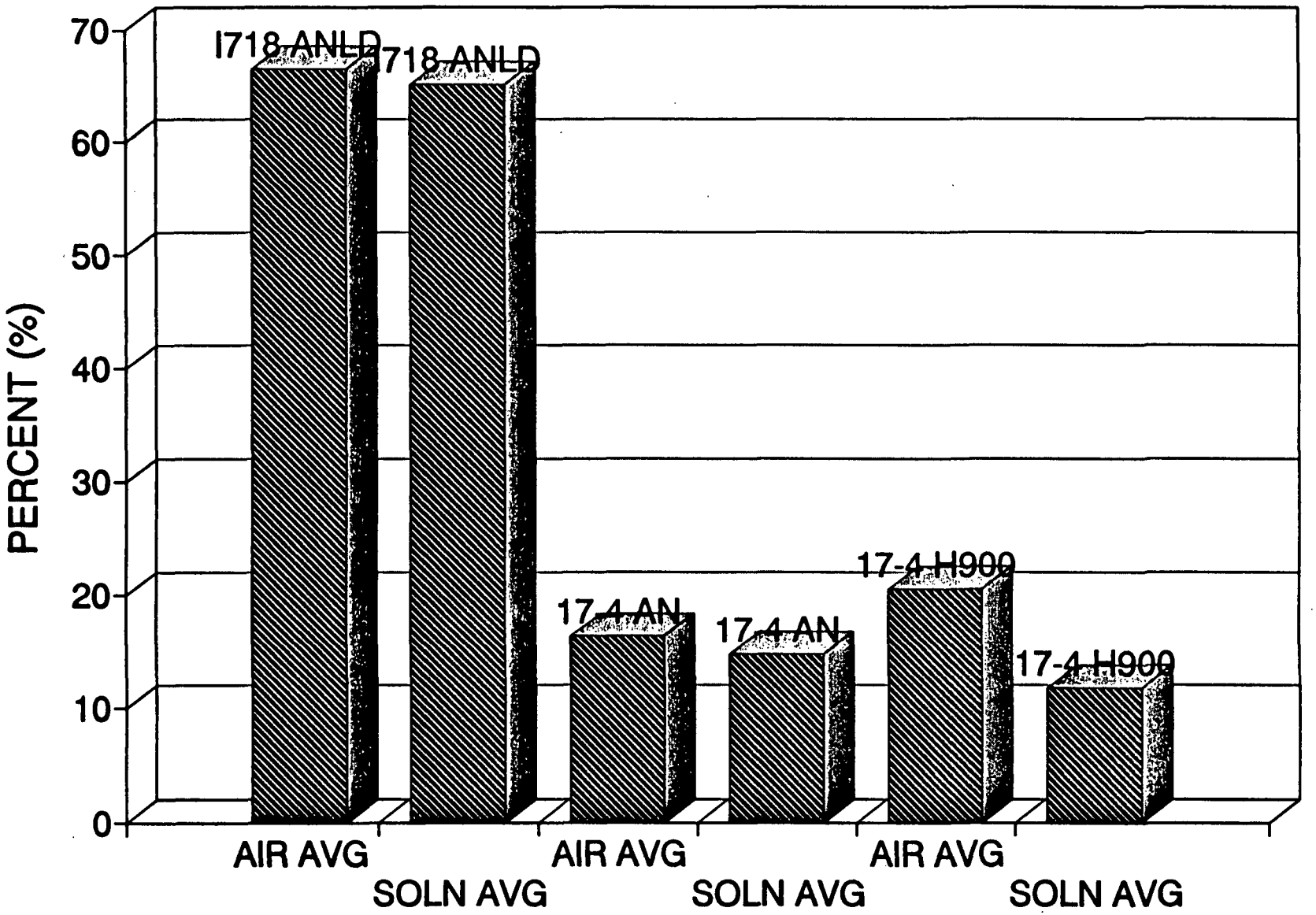

FIGURE 6.

STRAIN AT MAXIMUM STRESS

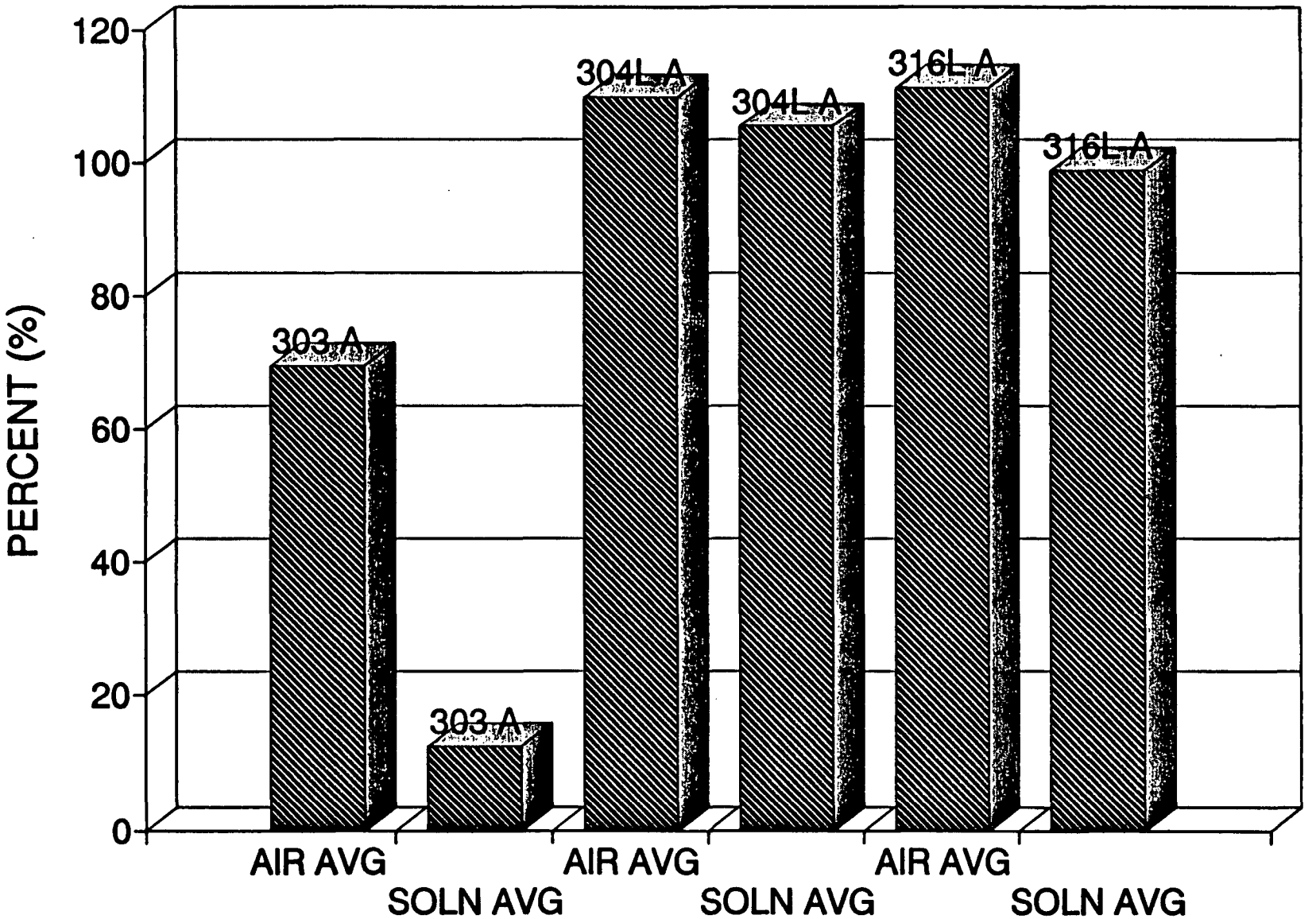

FIGURE 7.

STRAIN AT MAXIMUM STRESS

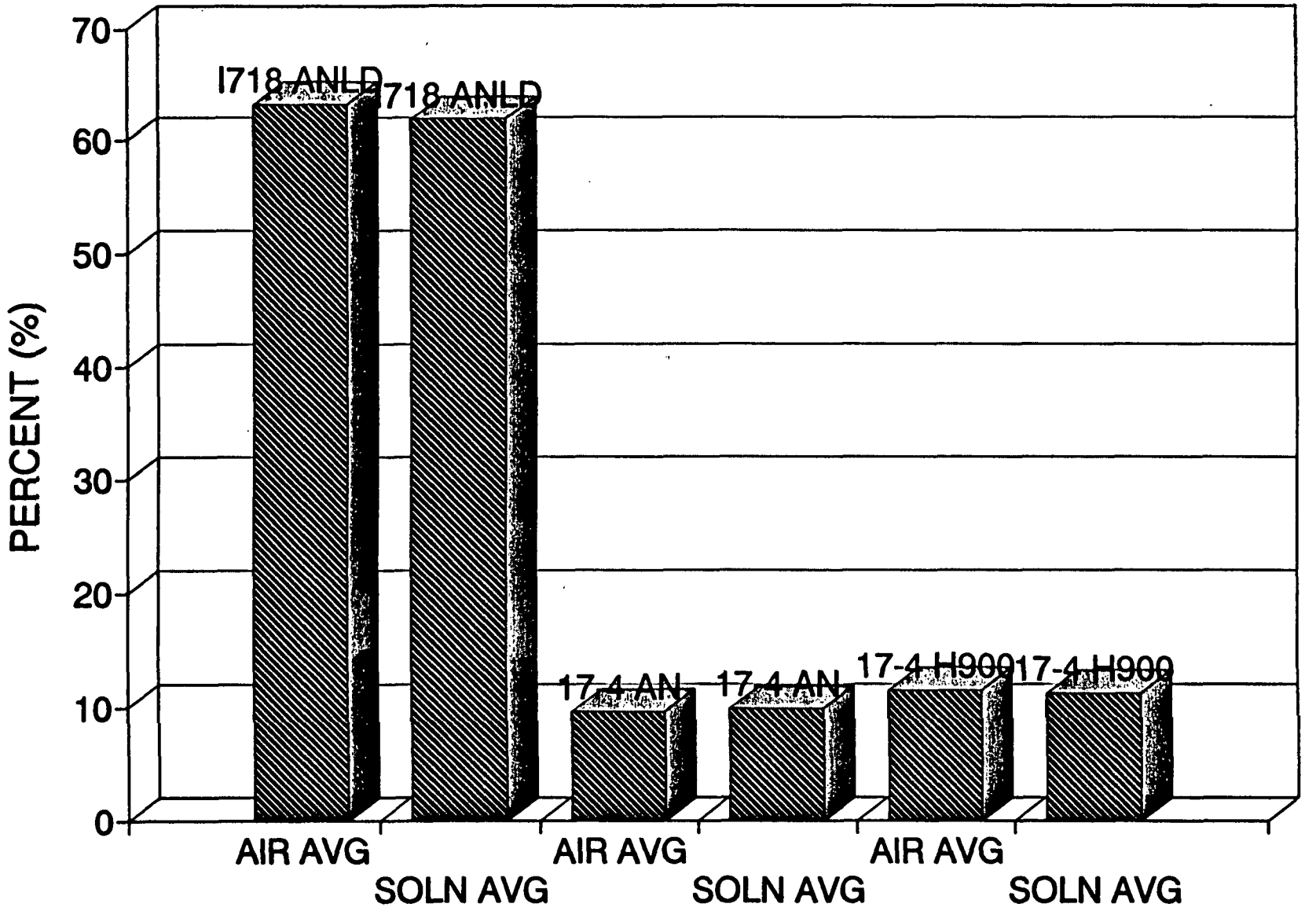

FIGURE 8.

REDUCTION IN AREA

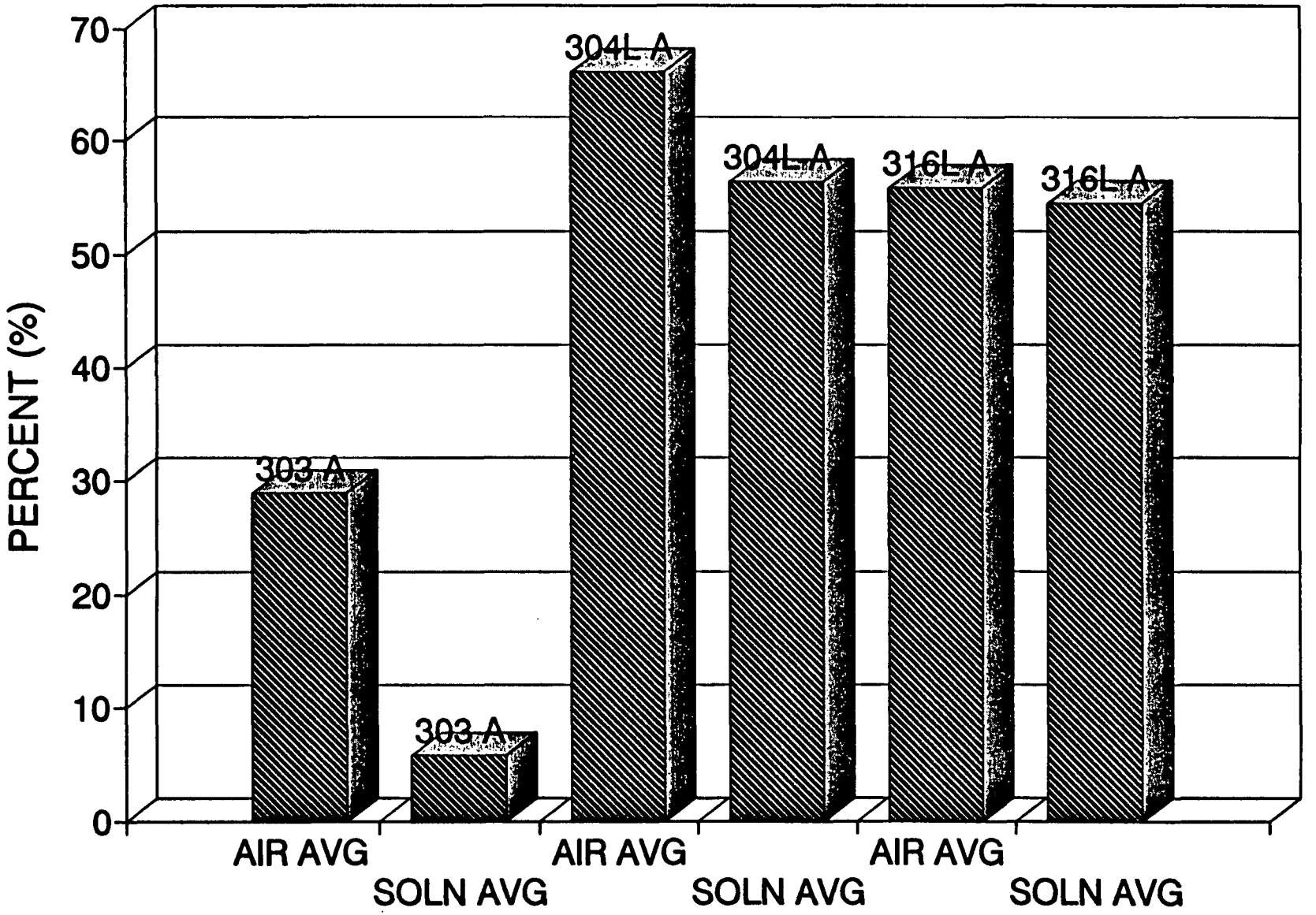

FIGURE 9

REDUCTION IN AREA

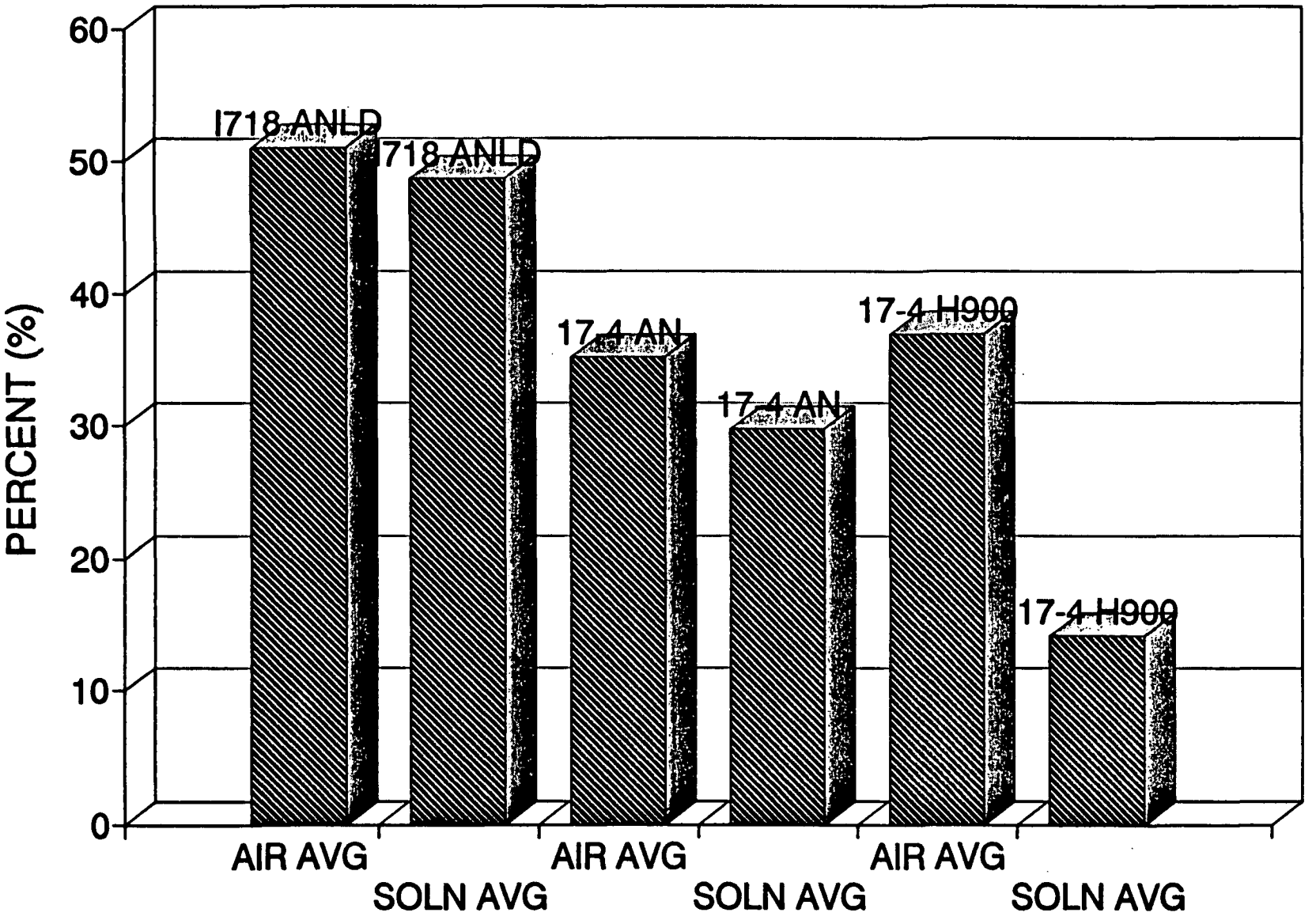

FIGURE 10.

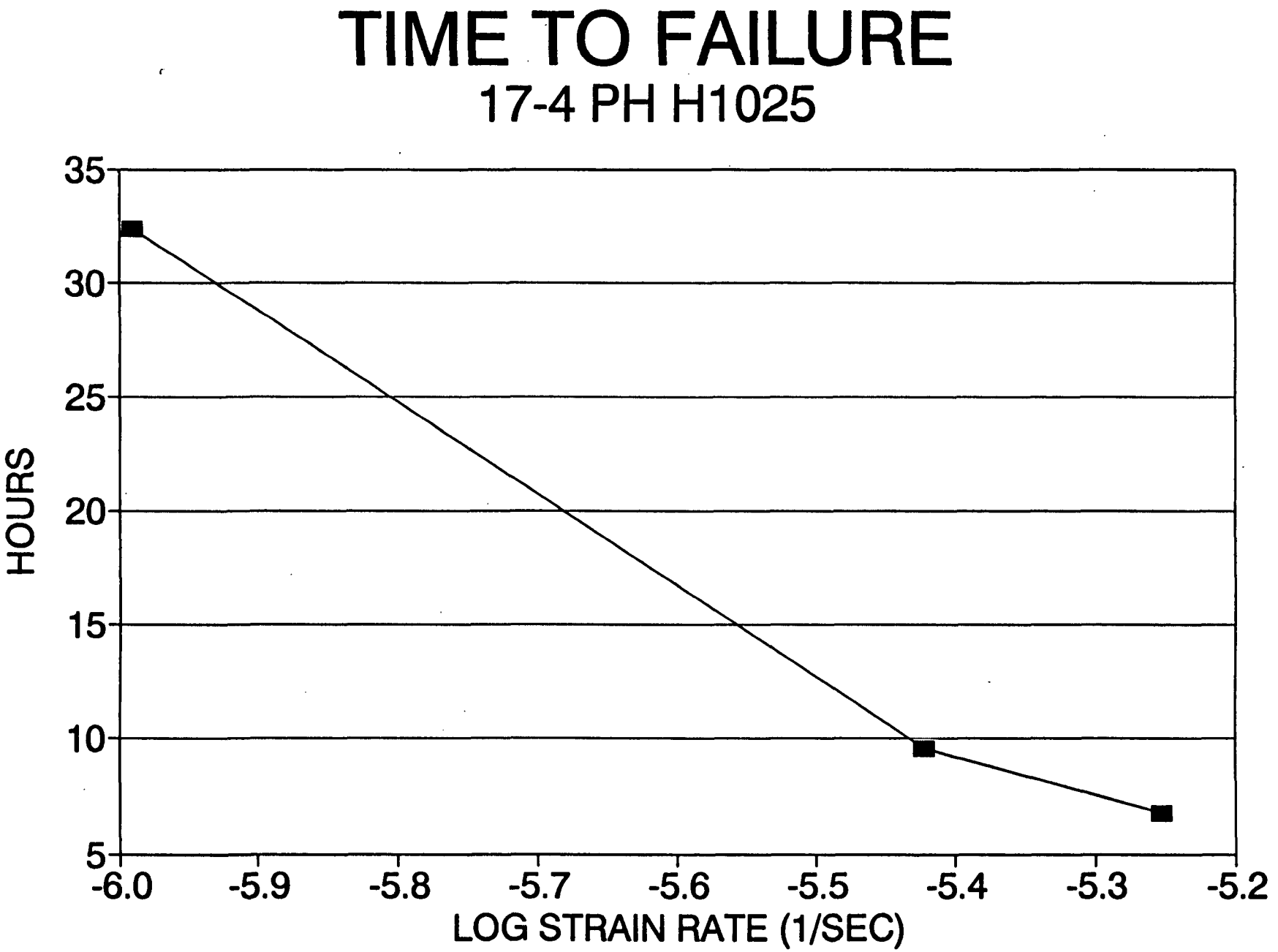
TIME TO FAILURE
17-4 PH H1025
HOURS
35
30
25
20
15
10
5
-6.0
-5.9
-5.8
-5.7
-5.6
-5.5
-5.4
-5.3
-5.2
LOG STRAIN RATE (1/SEC)

FIGURE 11.

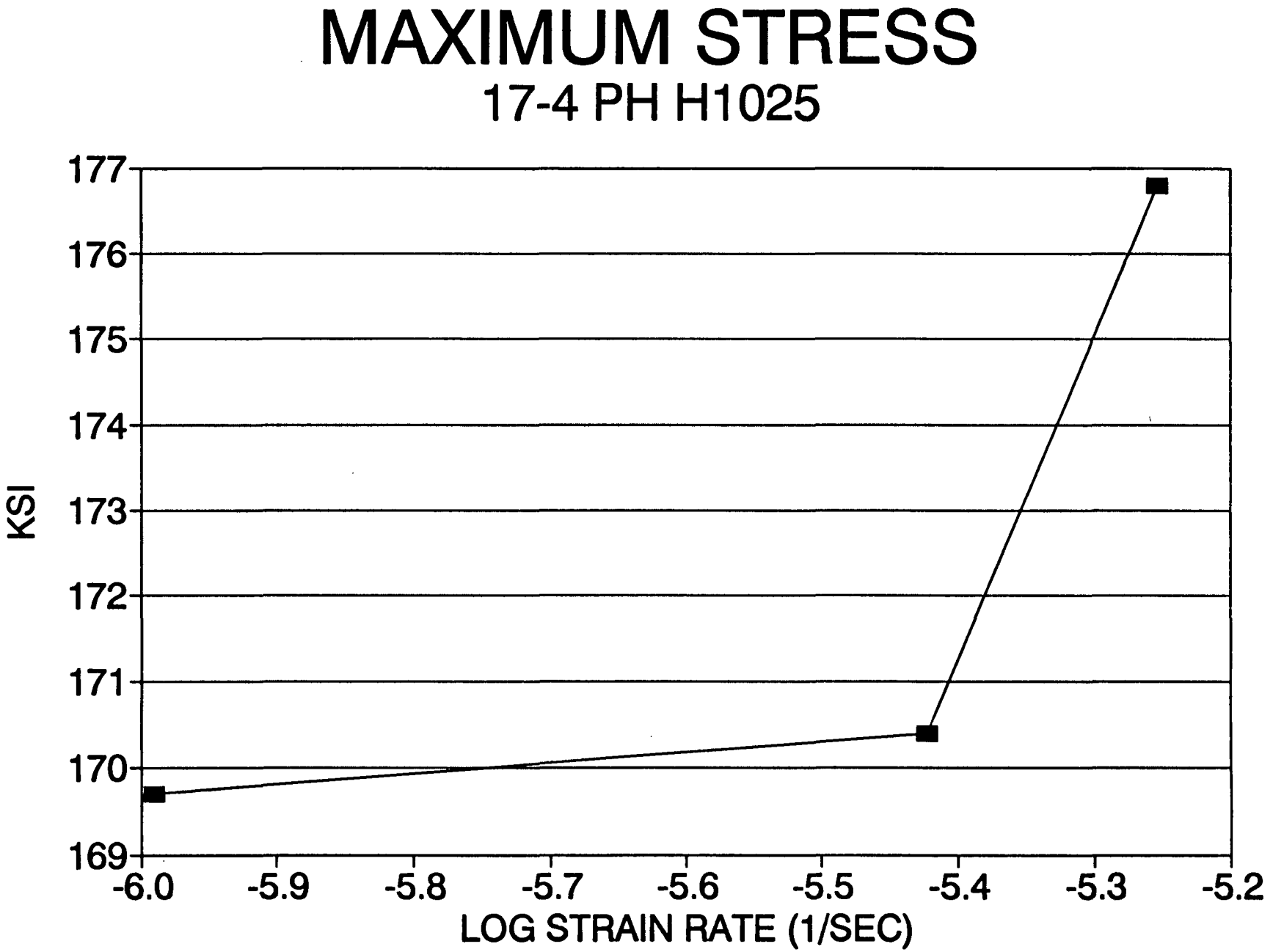
MAXIMUM STRESS
17-4 PH H1025
KSI
177
176
175
174
173
172
171
170
169
-6.0
-5.9
-5.8
-5.7
-5.6
-5.5
-5.4
-5.3
-5.2
LOG STRAIN RATE (1/SEC)

Figure 12.

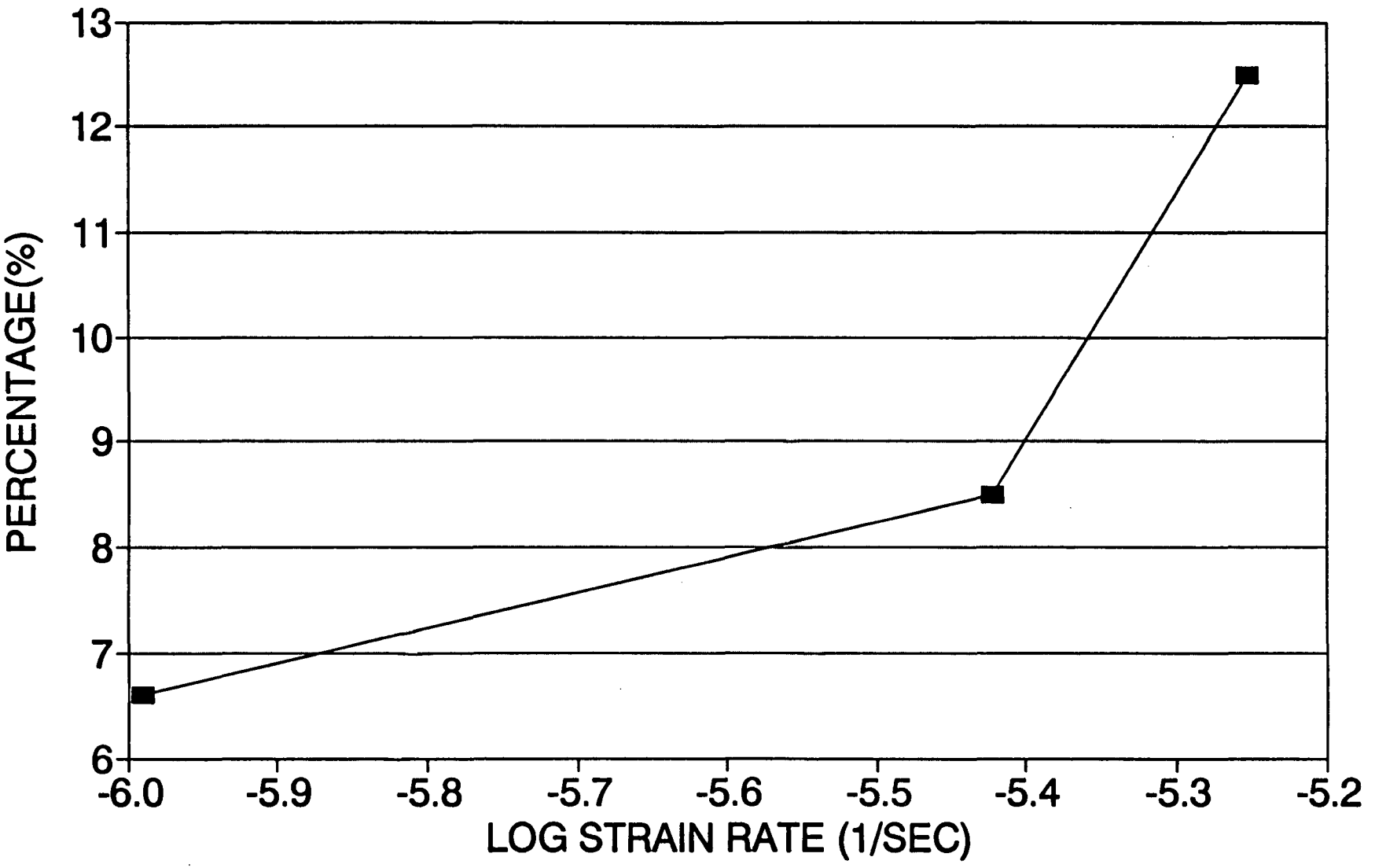
STRAIN AT MAXIMUM STRESS
17-4 PH H1025
PERCENTAGE(%)
13
12
11
10
9
8
7
6
-6.0
-5.9
-5.8
-5.7
-5.6
-5.5
-5.4
-5.3
-5.2
LOG STRAIN RATE (1/SEC)

FIGURE 13.

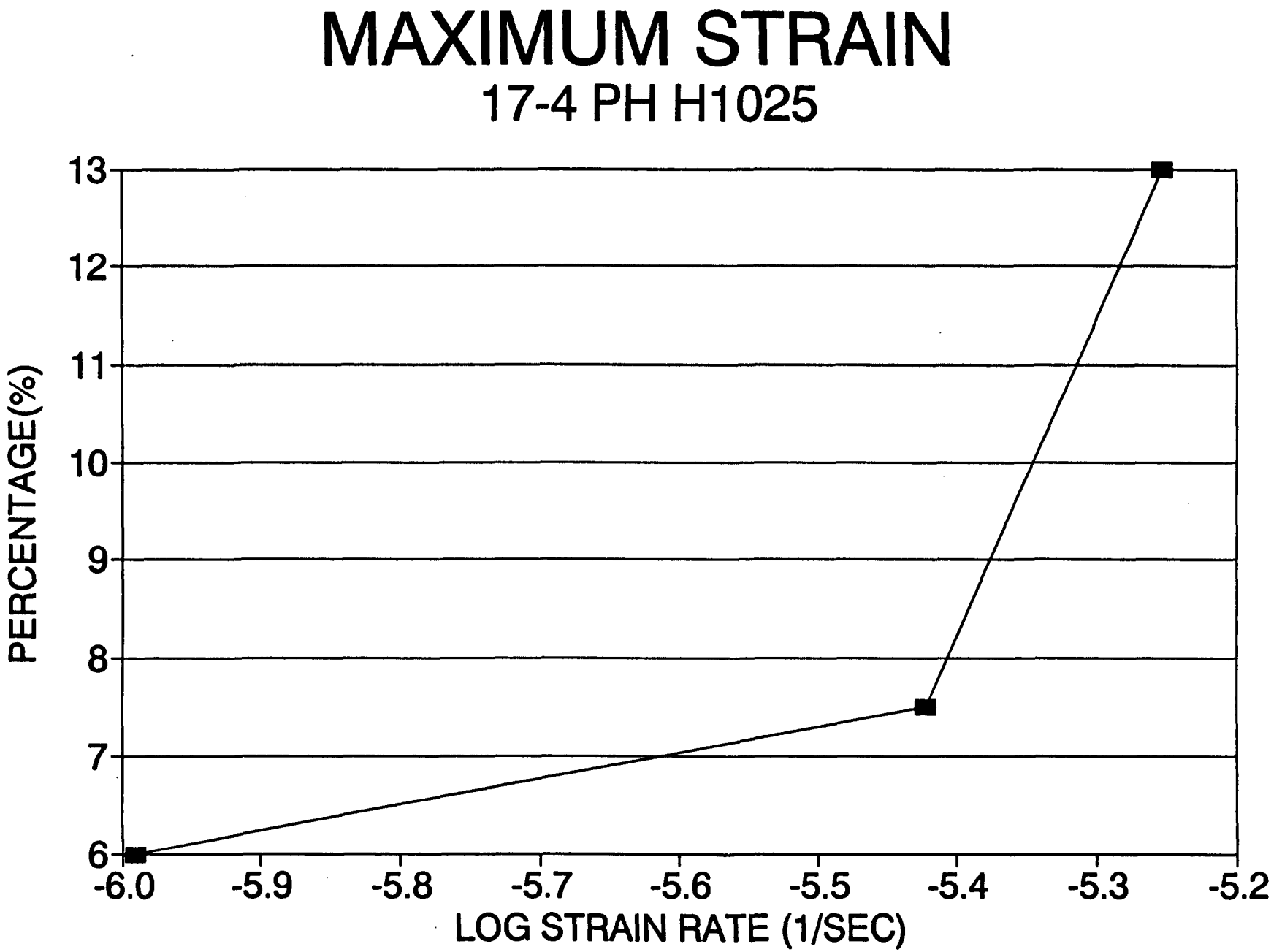
MAXIMUM STRAIN
17-4 PH H1025
PERCENTAGE(%)
13
12
11
10
9
8
7
6
-6.0
-5.9
-5.8
-5.7
-5.6
-5.5
-5.4
-5.3
-5.2
LOG STRAIN RATE (1/SEC)

FIGURE 14.

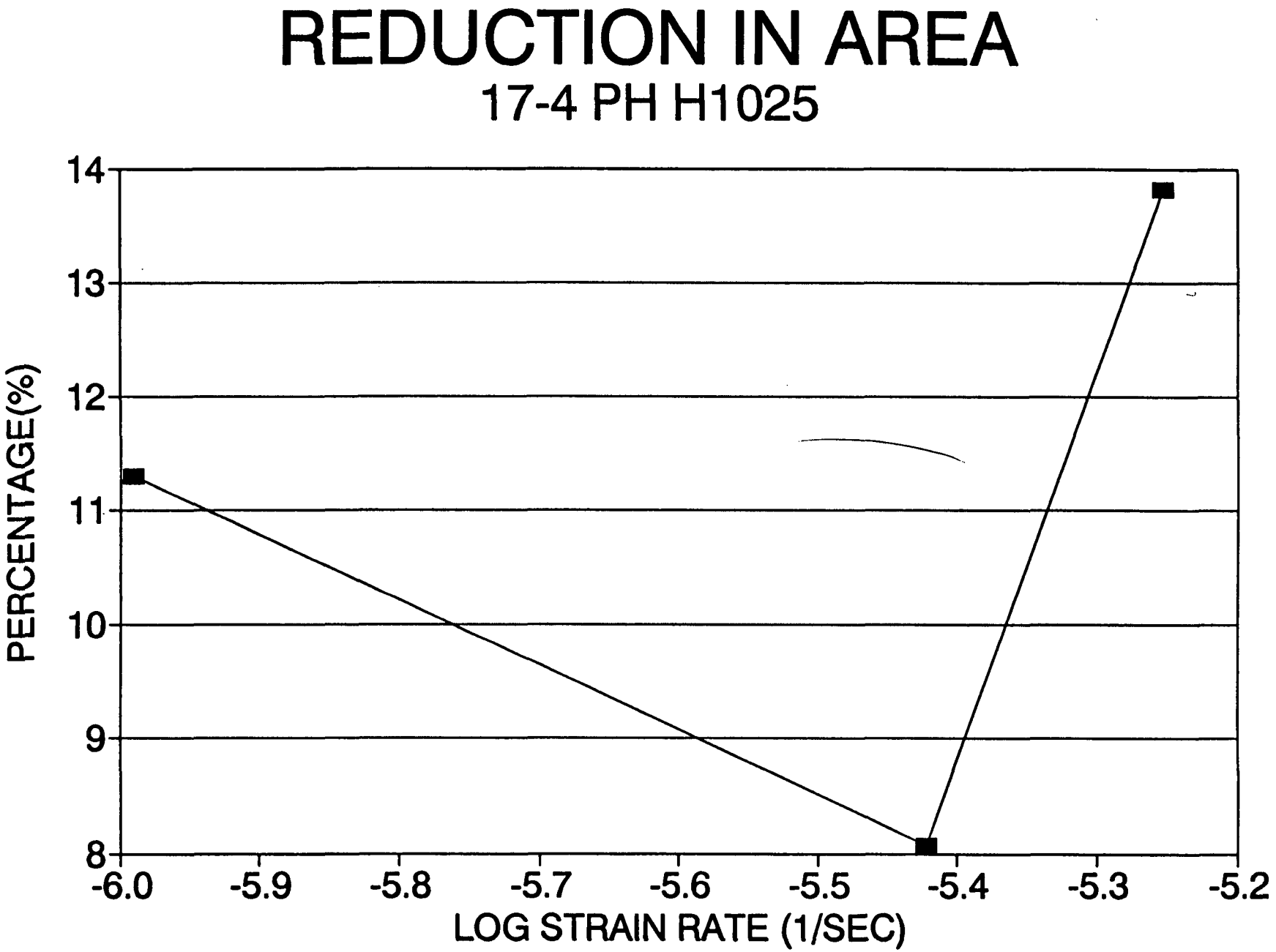
REDUCTION IN AREA
17-4 PH H1025
PERCENTAGE(%)
14
13
12
11
10
9
8
-6.0
-5.9
-5.8
-5.7
-5.6
-5.5
-5.4
-5.3
-5.2
LOG STRAIN RATE (1/SEC)

FIGURE 15.

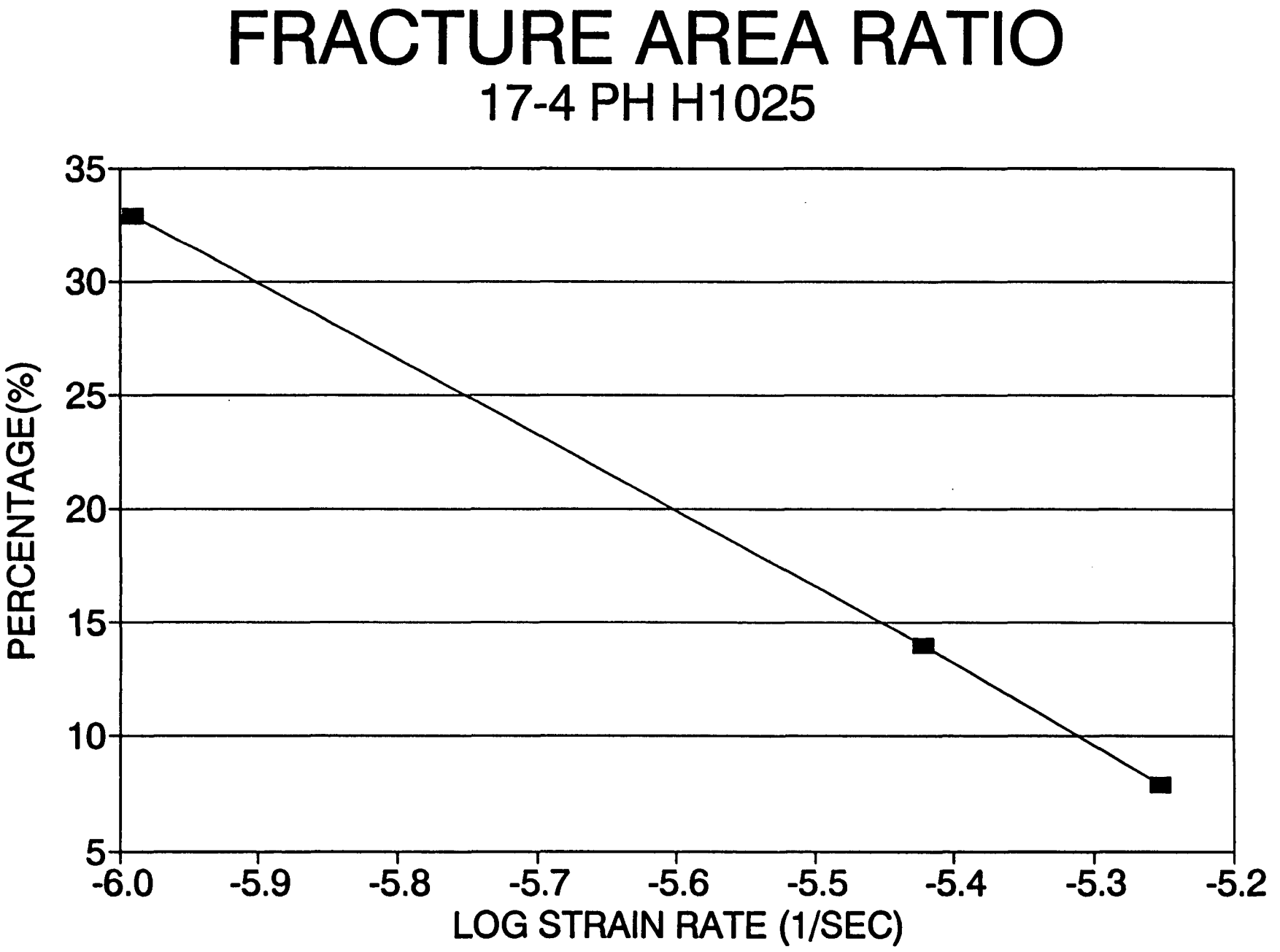
FRACTURE AREA RATIO
17-4 PH H1025
PERCENTAGE(%)
35
30
25
20
15
10
5
-6.0
-5.9
-5.8
-5.7
-5.6
-5.5
-5.4
-5.3
-5.2
LOG STRAIN RATE (1/SEC)

FIGURE 16.

strain rate the susceptibility increases. In the future all SSR tests will be conducted at strain rates between 1X10-5 per second and 1X10-7 per second so that SCC resistance can be determined at the most susceptible strain rate.

The fracture surfaces of the specimens pulled in solution show crack fronts that are parabolic in nature. These parabolas are longer than they are wide, suggesting that the crack advances quicker in the interior of the specimen than on the periphery, see figure 17. The interior of the specimen experiences high triaxial stresses during straining that the exterior does not. Regions of high triaxial stress absorb hydrogen more readily than regions of lower stress, suggesting that hydrogen may play a role in the cracking of the steels studied.

LOAD PULSING

Load pulsing consists of applying a base load to a tensile specimen that corresponds to a stress below that of the yield stress of the material under consideration. After the application of the base load, an impulse load is superimposed upon the specimen periodically. This impulse load blunts the tip of any crack, thereby producing the crack front markings as shown in figures 18 and 19. The distance between crack front marks, which are visible under SEM, are then measured. By knowing the time between impulses and the distance between crack front marks the crack velocity can then be calculated.

Load pulsing was conducted on 316 austenitic stainless steel

FURTHER EVIDENCE OF HIC!

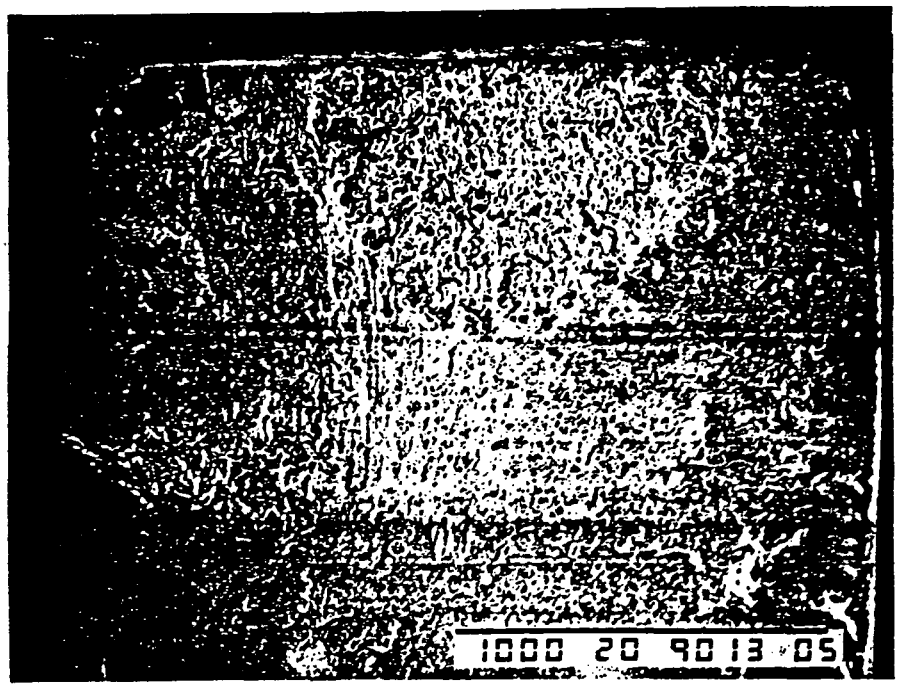

FIGURE 17.

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OF POOR QUALITY

TGSCC CRACK FRONT MARKINGS

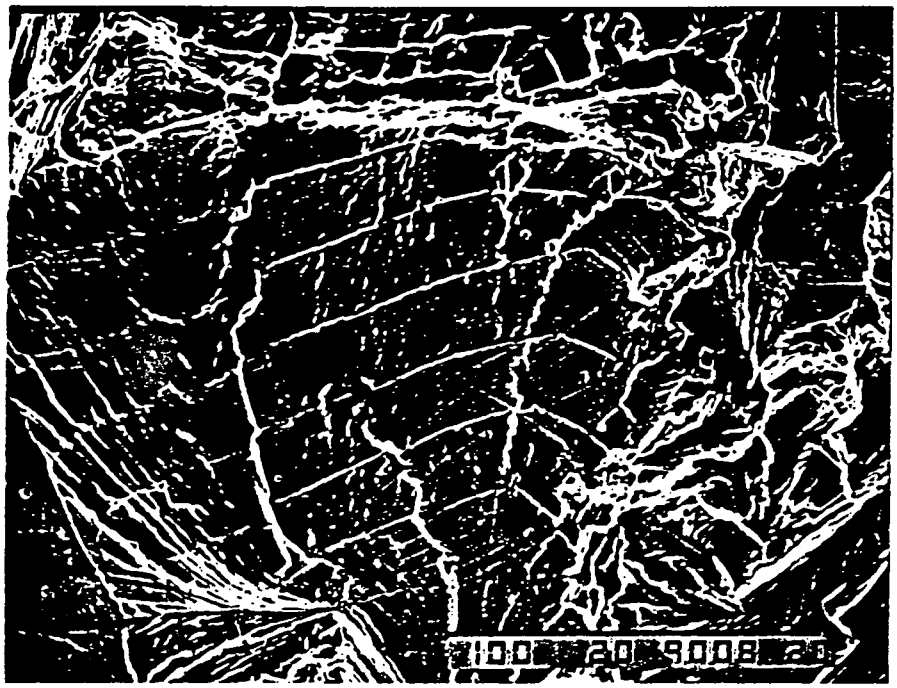

FIGURE 18.

IGSCC CRACK FRONT MARKINGS

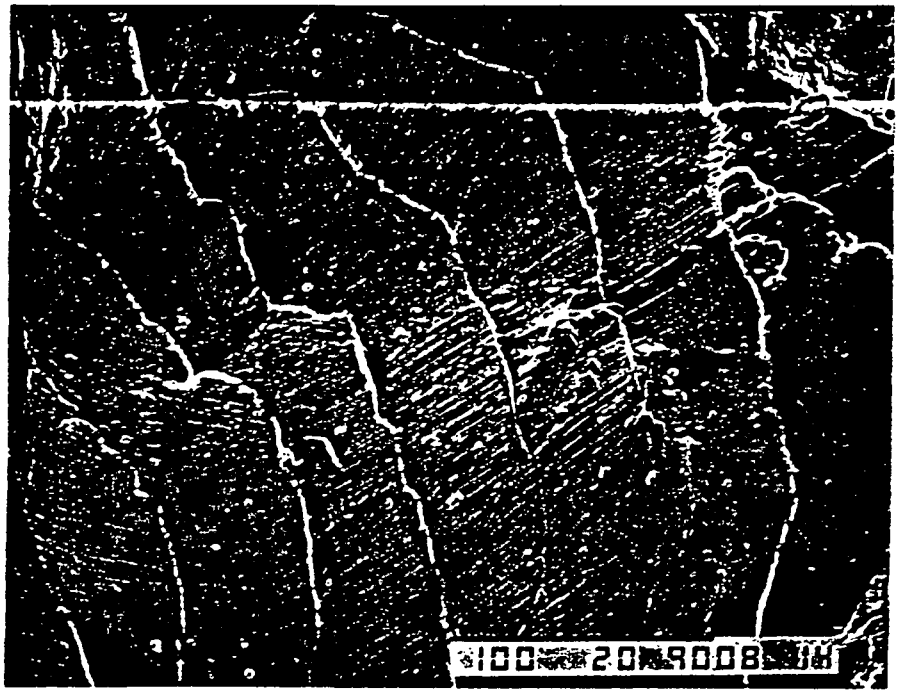

FIGURE 19.

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OF POOR QUALITY

in 15 weight percent lithium chloride solution, at temperatures ranging from 110 celsius to 170 celsius. The base load for these tests corresponded to 80 percent of the yield stress and the impulse load corresponded to 8 percent of the yield stress. The time interval between the impulse loads was 100 seconds.

Results of load pulsing indicate that the technique yields accurate crack velocities and that meaningful data can be obtained even if mixed mode cracking occurs as shown in figure 20. It was found that both TGSCC and IGSCC crack velocities follow an arrhenius relationship where crack velocity is a function of the temperature. The velocity of IGSCC was found to be 2 to 3 times that of TGSCC.

The activation energies for these events were determined from the arrhenius relationships, figures 21 and 22. The energy required to initiate SCC was determined to be 65 KJ/mole for TGSCC and 57 KJ/mole for IGSCC. Both of these energies correspond to that of hydrogen absorption in austenitic steel. The SSR data for the same alloy also indicated that hydrogen may be involved in the cracking process.

Another interesting result of the load pulsing tests is that the activation energies for both TGSCC and IGSCC are very close to the same value,yet the crack propagation rates are significantly different. This suggests that neither mode is more favorable than the other and that individual situation triggers one mode of crack propagation over the other.

MIXED MODE CRACKING

FIGURE 20.

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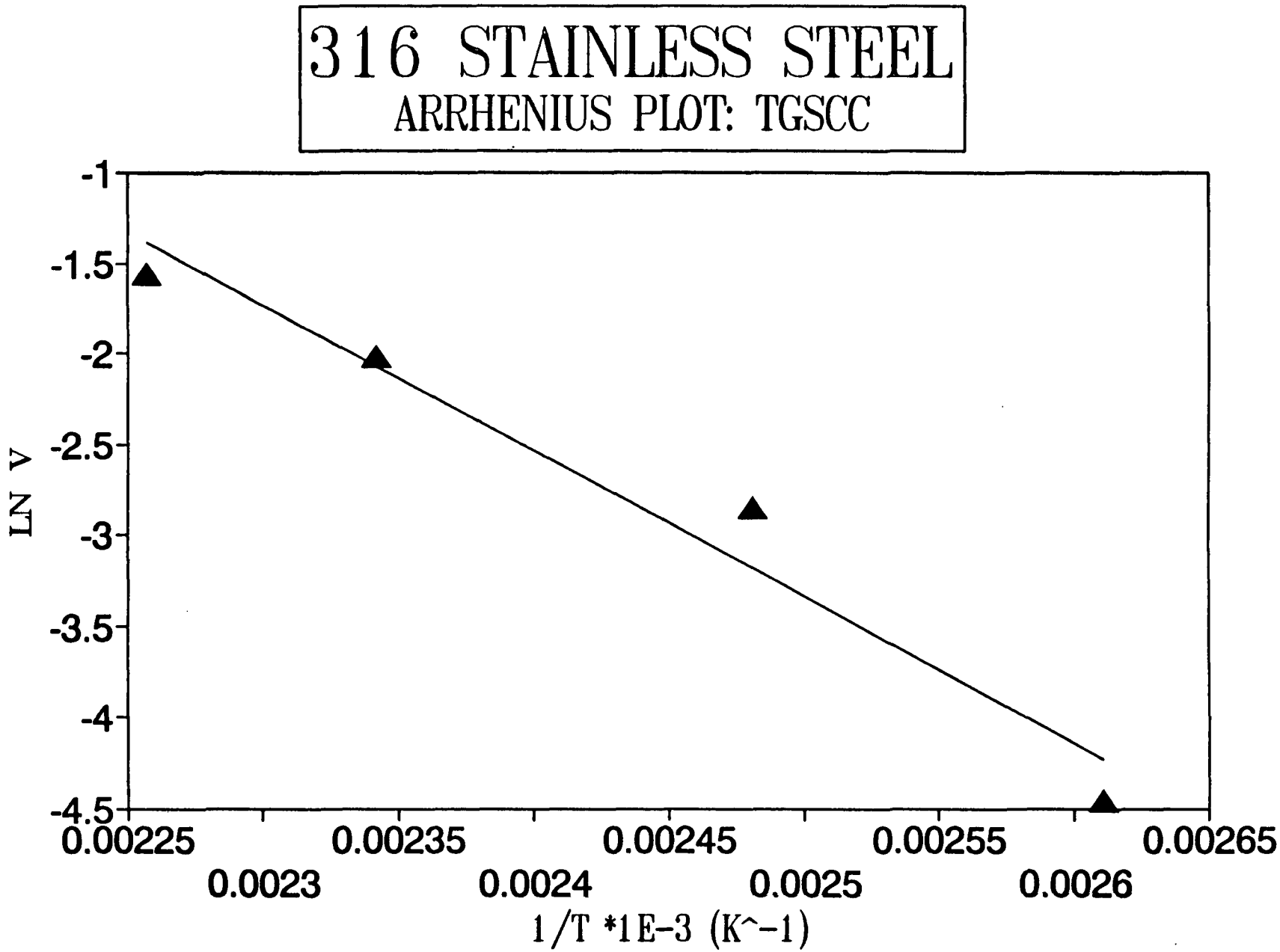
316 STAINLESS STEEL
ARRHENIUS PLOT: TGSCC
LN V
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
0.00225
0.00235
0.00245
0.00255
0.00265
0.0023
0.0024
0.0025
0.0026
1/T *1E-3 (K^-1)

FIGURE 21.

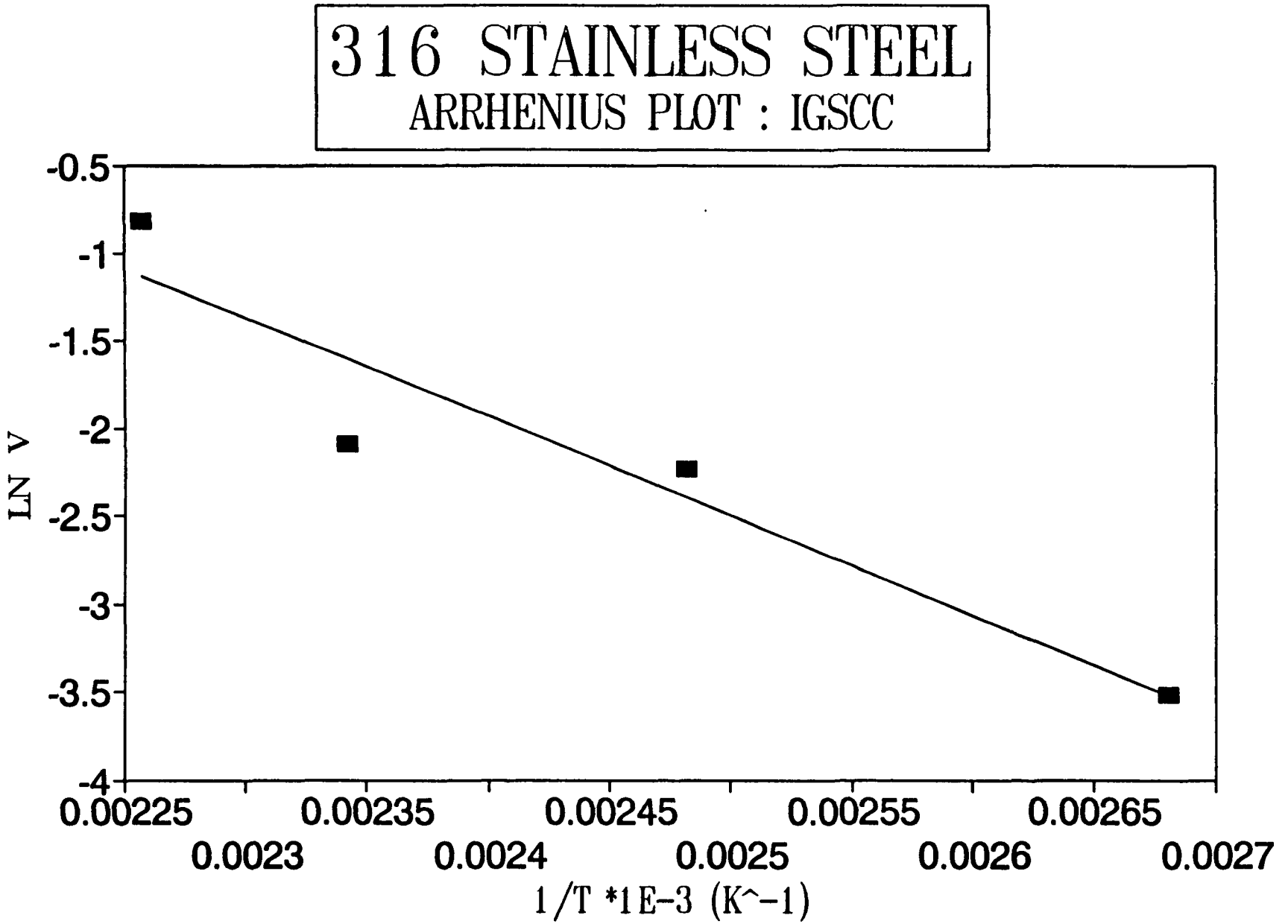
316 STAINLESS STEEL
ARRHENIUS PLOT : IGSCC
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
LN V
0.00225
0.00235
0.00245
0.00255
0.00265
0.0023
0.0024
0.0025
0.0026
0.0027
1/T *1E-3 (K^-1)

FIGURE 22.

LASER HOLOGRAPHY

The goals of the laser holographic project were to demonstrate its applicability to mechanistic investigations of SCC, provide conclusive evidence regarding the manner in which stress corrosion cracks propagate (i.e. continuous or discontinuous) and to quantify the similarities and differences between TGSCC and IGSCC. This technique involves taking a holographic image of the object under consideration and projecting this hologram back onto the object, the experimental setup is shown in figure 23. If there are any changes in the surface they will show up as fringes, these fringes can resolve changes as small as 0.3 microns.

Fracture mechanics specimens that exhibit out of plane deformation with changes in the stress intensity due to crack propagation were chosen for this project, the specimen geometry is shown in figure 24. The material for these specimens is cartridge brass, which has a composition of 30 percent Zinc and 70 percent Copper. The environments for these tests were 14.8 normal NH4OH, 14.8 normal NA4OH with Copper filings and 14.8 normal NA4OH with 6 grams per liter of Copper(I) oxide. The specimens were stressed by use of a wedge, then exposed to the test environment. A hologram is taken and projected onto the specimen, then a video camera is used to record the changes in the fringe pattern as a function of time.

Preliminary results show that the chosen alloy and specimen geometry crack easily at room temperature when stressed under constant deflection. The initiation period is short and the crack propagation rate is appreciable enough to allow real time holography. The solution composition effects the crack initiation

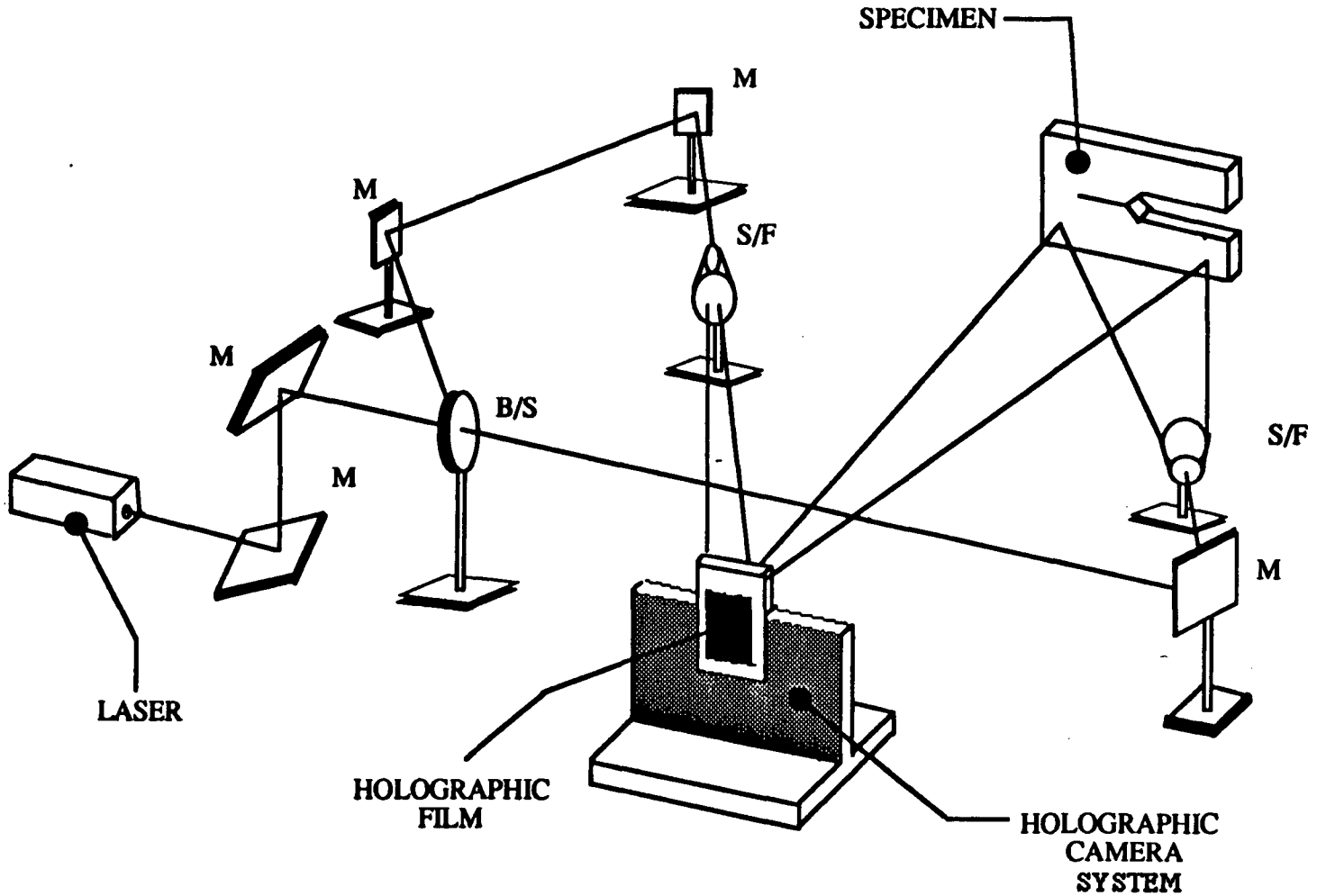
SPECIMEN
M
M
S/F
M
B/S
M
S/F
M
LASER
HOLOGRAPHIC
FILM
HOLOGRAPHIC
CAMERA
SYSTEM

FIGURE 23.

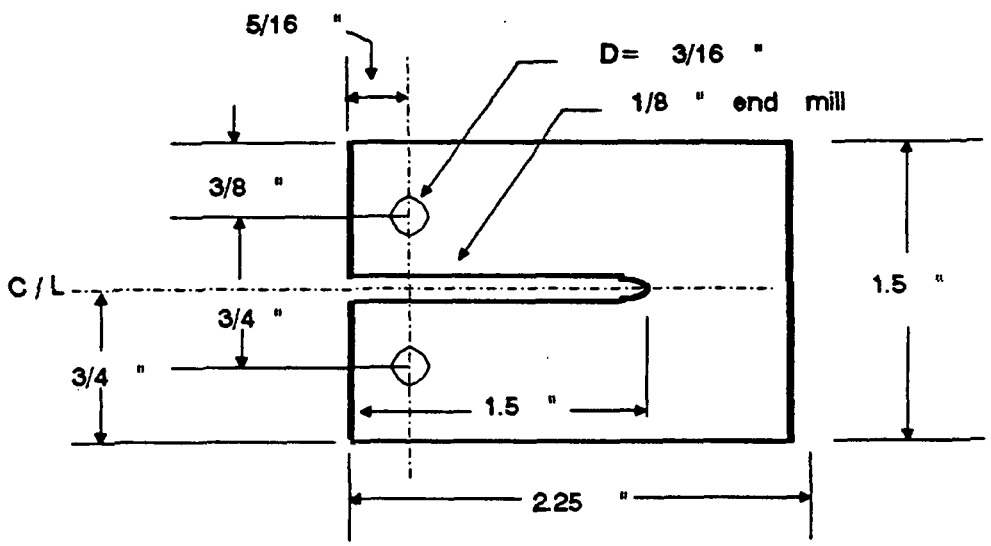

FIGURE 24.

period and the crack advances primarily intergranularly.

ELECTROCHEMICAL STUDIES OF PROTECTIVE COATINGS

Mr. Louis MacDowell (KSC) and Mr. Lee Zook, a UCF graduate student are currently studying panels of steel with various inorganic Zinc rich primer coatings that have been exposed to the beach testing site at KSC for a period of three years. Mr. MacDowell is also running AC Impedance studies on coated coupons exposed to aerated sea water for 1 to 2000 hours. AC Impedance is an electrochemical technique that can detect electrolyte penetration of a coating material before there are any visual signs of penetration. A comparison is being made of the three year exposure tests to the AC Impedance tests. It is believed that the AC Impedance data will yield the same information as the exposure tests and in much less time.

Small Amplitude Cyclic Voltometry and Electrochemical Impedance Spectroscopy tests will also be performed on similar specimens at UCF when current system upgrade is finished.

These tests are expected to continue through the second year of the cooperative agreement. It is hoped that insight will be gained into the mathematical model appropriate to the actual electrochemical interface by comparison to postulated electrical circuits. When a valid equivalent circuit is found, the behavior of the system can be deduced by performing calculations for conditions other than those which were measured.

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NASA/Kennedy Space Center
and
University of Central Florida

Project 6
Productivity Improvement Techniques
Account # 16-24-201

Phase I Final Report

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3. Workstand Design Interim report
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Executive Summary

Thermal Protection System (TPS) is a significant limiting factor consuming substantial resources in the shuttle processing at KSC. The use of industrial engineering principles in the development of new processing methods should increase productivity, decrease the use of resources while increasing the reliability and efficiency of operations.

The overall objective of this project is to increase productivity and reduce labor intensiveness in the TPS processing operations through the application of existing and new technologies including automation, voice recognition, photomechanics, and knowledge based systems.

Phase I objectives are as follows:

- Establish a research team for the project.
- Identify potential areas of improvement in TPS and the Tile Automation System (TAS), and develop strategy for the 3 - year effort.
- Resolve problems associated with the use of Voice Entry System (VES) under development at KSC and develop a Training Strategy and an Implementation Strategy.
- Analysis and Design of two-person workstand for tile processing (overhead operations)
- Investigating the feasibility of using photomechanics/laser digitization for Cavity digitization.

Research Teams, Assignments and Approach:

For each of the three study components (Voice Data Entry, Workstand Design, and Cavity digitization) a graduate student with either background or specialty in the area of study was teamed up with one faculty member to research the component and develop solutions. In the initial phase of the study a one page document was produced for each component detailing the objective, procedure to be followed, and the expected outcome of the study. Occasionally a team could be assisted by undergraduate students as part of their assignments in a senior design class in the industrial engineering program. The study required several visits per week by the research team to KSC facilities. The approach included meeting with NASA - and Lockheed Space Operations Company (LSOC) personnel, interviews with managers and tile technicians, and reviewing existing documentation.

Potential Areas of Improvement in TPS and TAS:

A 3-year effort was outlined, and formulated in a proposal to KSC, as part of phase II of the cooperative agreement. The details of the proposed areas of research is in a separate section of this report. The proposal points to the need for a feasibility study both technical, operational and economical before embarking in any automation

process.

Voice Data Entry System (VDES).

One possible application of VDES is in the step and gap measurement process (P-310) which is vital to the assurance of high quality for the TPS. In this process tiles must be measured and recorded for step and gap when work, such as tile replacement, tile removal and door and access panel opening, is performed, and which may alter the step and gap measurements. The expected time savings from the use of this technology is a reduction in recording time from 173 minutes to 43 minutes per tile, which is directly related to the productivity improvement in TPS. In another project the VDES hardware was acquired, and the P-310 software was developed by LSOC.

Successful implementation of the VDES requires training of the system to recognize the user's voice as well as training the user to work with the system. Introduction of the system to the shop floor requires an implementation strategy to insure data integrity and to allow for system testing.

A training strategy was developed for various levels of expected users (managers, technicians, quality control inspectors, and trainers). For each level a number of training scenarios were developed. Considerations were given in the scenarios to include typical cases which are representative of what may face the system user.

The implementation strategy calls for gradual introduction of the system in parallel with the existing manual system for 4 mission flows (each orbiter processing sequence is referred to as a flow) and compare data entry methods. Gradual implementation would follow for 3 to 4 flows before cut off of the current manual system. This will allow for complete training of all involved users. The details of the training and Implementation Strategies is in a separate report in this document.

The research team conducted vendor survey for voice entry systems. A microcomputer based system was selected for experimentation with a radio signal in the UCF laboratory to counter the constraints imposed on processing in the OPF environment.. The system was selected based on the amount of vocabulary which can be stored, its compatibility with the expected date type to be transferred between the user and a computer, and constraints related to the use of wire cables in the Orbiter Processing Facility.

Currently, efforts are underway to identify and develop the necessary software for the use of the VDES in other areas of TPS processing.

Workstand Design:

The research team has performed literature and vendor searches, as well as an analysis of tasks performed from the two-person workstand. The analysis showed little

data exists for work performed in overhead positions. A set of requirements for new designs include: safe access to lower orbiter surfaces in range of 8 to 12 feet above the OPF floor, easy height adjustment and stand movement, rigidity and stability for precise work, ergonomic considerations for unusual postures, and considerations for equipment and paperwork access and storage. Specific requirements for the workstand include continuous height adjustment accomplished from working position, postural support for tasks performed, provisions for special equipment and access to narrow spaces and compliance with NASA SW-E-0002, NSTS 08242, and MIL-STD-1427C. Three designs are currently being studied by the research team. The research is continuing towards building a prototype of a portable seat design which may be used in the existing workstand. Modifications in the height adjustability of the current stands would eliminate the need for more than operator for height adjustment. The details of the study is in a separate report in this document.

Cavity Digitization:

The objective of this research component is to replace the current tile cavity "splashing" process with an integrated, non-contact, 3-D cavity measuring system that directly feeds a numerically controlled machine for tile manufacturing. The first phase of this study is to conduct a technical feasibility study for the elements of such system. Studying the various techniques shows two promising methods for such applications (Moier and laser scanning). Vendor survey resulted in identifying limited sources for such specialized equipment. Those vendors were contacted and effort is underway to find which equipment is adequate for the cavity application. A sample test is being designed to assess the validity of the vendor's claimed accuracies viz-a-viz design requirements.

In a parallel study aimed at identifying problems associated with on-the-job-orbiter application, a number of problems were identified. These include static and dynamic accuracies, the various positioning requirements for the digitized tool and the difference between digitizing and mapping surfaces vs that of a cavity. Clearly, any adopted technology must be able to overcome these problems for successful implementation.

In a related effort, the cavity digitization was formulated as a research proposal and equipment funds were secured from the Florida High Technology and Industry Council (FHTIC) for experimentation on a selected technology.

A research report for partial fulfillment of a Master of Science degree of the assigned member of the research team was produced summarizing the findings of the technical study and is part of this document. A number of graduate students are now working on the design of experiment to evaluate and test the validity of the digitization, the conversation of the digitization data into a CNC machine instruction for tool guidance, and resolve the identified problems associated with the application on the orbiter.

Technology Transfer:

Eight Technical papers/presentation have been submitted/conducted in related

conferences. Seven graduate students either graduated or currently conducted their thesis research using topics of this project. Three technical proposals have been submitted, (two funded, and one pending). Three technical Interim reports were submitted to NASA/KSC, and three progress representation were performed. Three faculty members are currently working in this project.

I. Team Formulation and Task Assignments

1. Phase 1 Working Papers
2. Phase 2 Working Papers

UNIVERSITY OF CENTRAL FLORIDA
INDUSTRIAL ENGINEERING PROJECT
UCF/KSC SUMMER COOP AGREEMENT

CAVITY DIGITIZATION / PHOTOMECHANICS STUDY COMPONENT

Phase I - Summer, Fall 1989

INTRODUCTION:

Current effort at KSC involves new methods for tile replacement. Manufacturing damaged standard tile may be done by using the original CNC program used for original tiles. However, for nonstandard/special tiles, a mold is used to configure the cavity (splashing). This mold is used to produce a CNC program for a tile cut. This process is lengthy and time consuming and the quality of the produced tile usually requires on-site adjustment.

The photomechanics is relatively new and rapidly progressing field. Its use in operations at KSC may have an impact on the production of damaged tiles. The idea is to use photo processing and/or laser digitization tools to replace the current molding process. Since the process is computer based, cavity data may be fed directly to a milling machine for tile manufacturing.

The objective of this project component is to study the feasibility of incorporating the use of photomechanics in tile processing and evaluate its effect on productivity at KSC.

The study will be both technical and economic. The technical study will address the state-of-the-art of available equipment, while the economic study will concentrate on the costs associated with photomechanics vs. manual methods.

OBJECTIVE:

Carry technical feasibility study to identify methods/techniques and problems associated with the use of photomechanics for tile processing.

PROCEDURE:

Procedure will include a background study and literature search as well as a manufacturer's search for photomechanic/laser digitization equipment.

OUTCOME:

Technical report documenting the searched state-of-the-art methods, available equipment and comparative study on their performance in the intended application.

UCF TEAM INVOLVED: Hosni, Swart, Nasser

UNIVERSITY OF CENTRAL FLORIDA
INDUSTRIAL ENGINEERING PROJECT
UCF/KSC SUMMER 1989 COOP AGREEMENT

PHOTOMECHANICS COMPONENT

Schedule (June - November 1989)

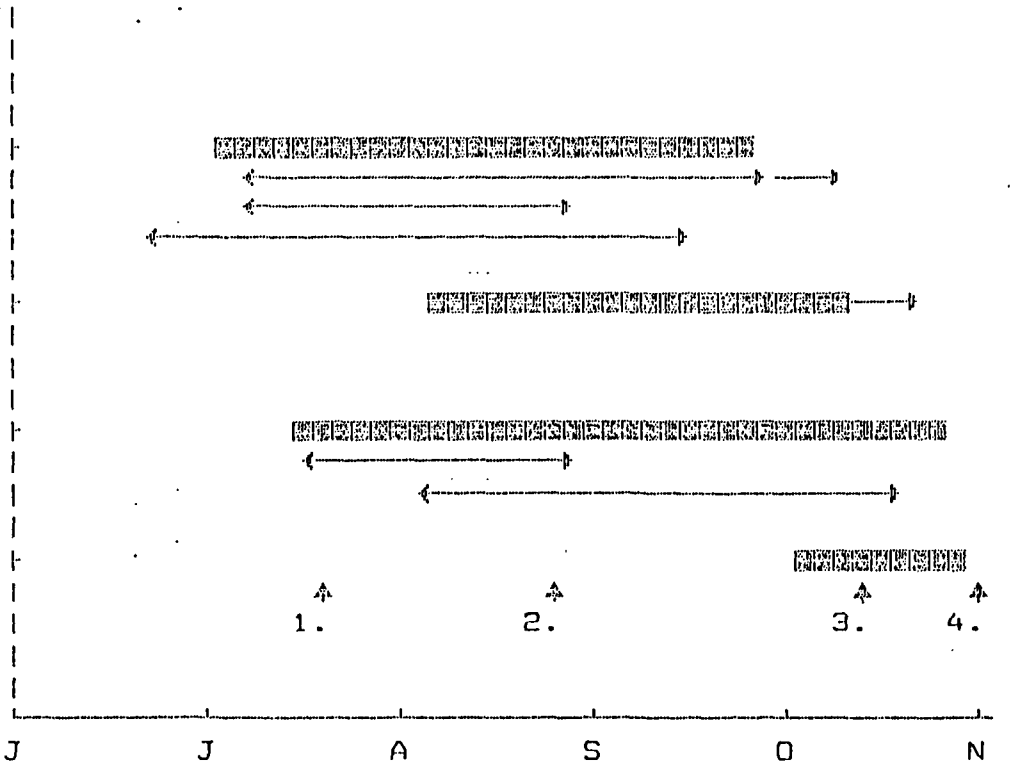
ACTIVITY :

1. Preliminary Analysis
   - Lit. search/ CREOL
   - Vendor search
   - Knowledge Acquisition

2. Experimentation
   - Experiment Design
   - Equipment specs.

3. FLHITEC Proposal
   - Industry support
   - Prop. preparation

5. Reporting
   1. UCF (7/17) Present.
   2. KSC (8/25) Present.
   3. KSC (10/1) Prelim. Rt.
   4. KSC (11/1) Final Rpt.



UNIVERSITY OF CENTRAL FLORIDA
INDUSTRIAL ENGINEERING PROJECT
UCF/KSC SUMMER, 1989 COOP AGREEMENT

VOICE ENTRY TRAINING COMPONENT

INTRODUCTION:

Current effort at KSC involves implementation of voice data entry in the Tile Processing System (TPS). The hardware and software have been developed. The system is now ready for its initial application. First stage of implementation includes training of potential users (technicians, quality control, management supervisors). The next stage includes implementation on the shop floor and assessment of system performance. The third stage will include resolution of problems associated with implementation.

OBJECTIVE:

The objective of the study is to develop a training strategy as well as an implementation strategy for the voice data entry system.

Training strategies will be tailored for the different levels of personnel (first timers and experienced users) to operate the system. Training manuals for both instructors and trainees involving typical scenarios will be developed.

Comparative study between different implementational policies will be carried out to determine an optimal strategy.

PROCEDURE:

Activities will be coordinated with the development team and training specialists at KSC. Procedure will include examination of similar experiences as well as experimentation with different strategies using the actual system and/or simulated data entry station.

OUTCOME:

1) A complete technical report documenting the training and implementation strategies as well as results obtained from training sessions expected by end of project period.

2) Training manuals for voice data entry systems for instructors and trainees will be completed.

UCF TEAM INVOLVED:

Hosni, Swart, Scarboro, Creech.

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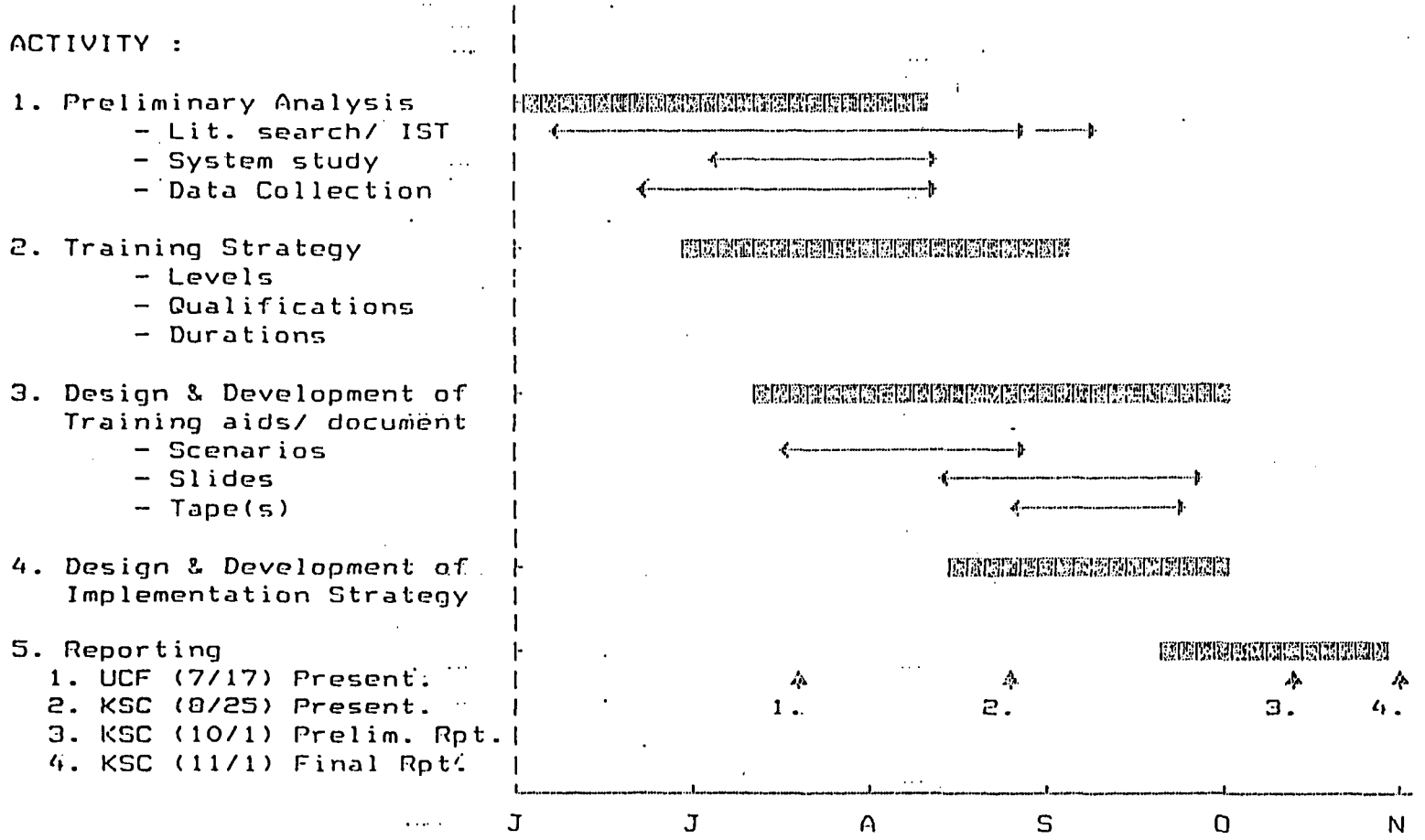
VOICE ENTRY TRAINING COMPONENT

Schedule (June - November 1989)



UNIVERSITY OF CENTRAL FLORIDA
INDUSTRIAL ENGINEERING PROJECT
UCF/KSC SUMMER, 1989 COOP AGREEMENT

WORKSTAND DESIGN COMPONENT

INTRODUCTION:

Lockheed TPS technicians currently use a number of different workstand configurations to accomplish the numerous tasks involved in orbiter TPS inspection, repair, and replacement. Although tile and other thermal protection materials are used on the entire orbiter exterior, work involving the lower flight surfaces appears to be the most challenging to the tile technicians since a great deal of work is done "out-of-position," i.e., upside-down.

Access to the lower surface tile is achieved from floor level by using various designs and sizes of workstands, some portable, some not. Initial information indicates that most often, one or two technicians are involved in a given task. Preliminary interviews with technicians indicate that considerable improvement can be made in the design of the workstands to enhance both task accomplishment and technician safety.*

The current rolling workstands do not contribute to worker safety, are ergonomically unsuitable for the tasks performed from them, and will not accommodate hardware components being developed in the tile automation program.

OBJECTIVE:

The UCF Research Team, in coordination with NASA and Lockheed personnel intends to design an ergonomically improved workstand with greater stability, height adjustability, and scarring to accommodate all currently used, as well as proposed, tooling and equipment.

PROCEDURE:

Design criteria will be generated through task observation, literature search, current design review, and solicitation of vendors manufacturing devices with transferable technology. All design constraints peculiar to OPF operations will be reviewed and complied with.

OUTCOME:

1) Generation of complete technical specifications for an improved 2 person, portable workstand.

2) Alternative design approaches with an evaluation of each (advantages, costs, etc.), contrasted with a similar evaluation of the current stand design.

UCF TEAM INVOLVED:

Hosni, Swart, Scarboro, Creech.

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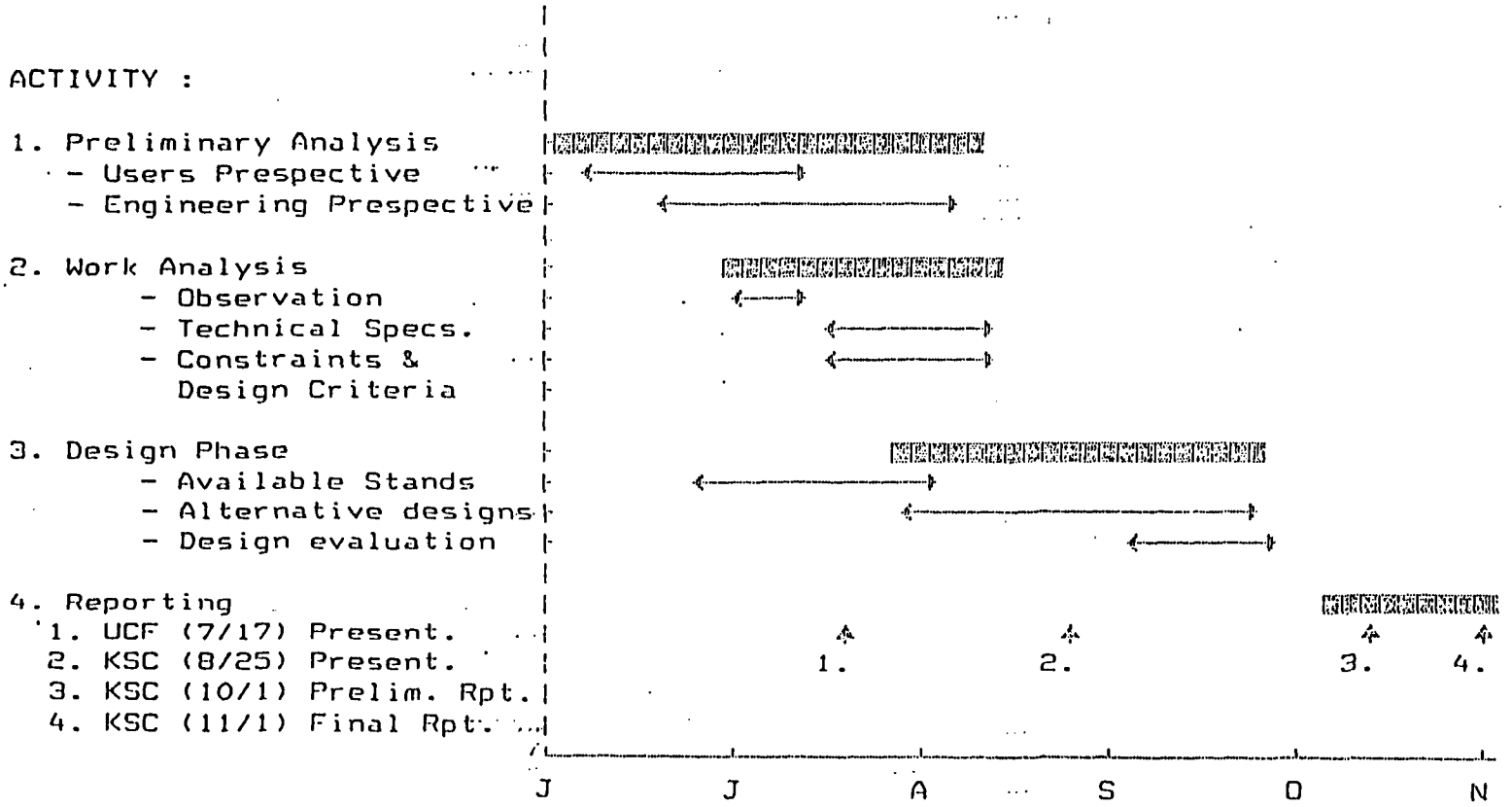
WORKSTAND DESIGN COMPONENT

Schedule (June - November 1989)



UNIVERSITY OF CENTRAL FLORIDA
INDUSTRIAL ENGINEERING PROJECT
UCF/KSC COOPERATIVE AGREEMENT

CAVITY DIGITIZATION / PHOTOMECHANICS STUDY COMPONENT

Phase II - Spring, Summer 1990

INTRODUCTION:

The objective for the first phase for this component of the study, as outlined in Phase I working paper, have been met. An MS research report (containing partial results) and a research proposal to Florida High Tech. Council, document the outcome.

The purpose of this working paper is to outline the objective, procedure, and expected outcome for Phase II of the study.

OBJECTIVE:

Set up an experimental (laboratory) model for a cavity digitization device to be linked to an NC milling machine.

PROCEDURE:

- Team members become familiar with the digitization technology and previous effort.
- Select 3-4 potential equipment manufacturers/vendors.
- Decide on type of experiment.
- Establish technical cooperation between parties (UCF, KSC, Vendor (s).
- Acquire hardware and set up an experimental model.
- Document findings, results, etc., in a technical report.

OUTCOME:

1) An experimental model.

2) Technical report documenting the findings of this phase (experimental results) and suggested solutions to an on-site implementation problems.

UCF TEAM INVOLVED:

Hosni, Labiche, Hwang (Jimmy).

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UCF/KSC COOPERATIVE AGREEMENT

WORKING PAPER FOR PHASE II - SPRING AND SUMMER 1990

VOICE DATA ENTRY SYSTEM (VDES) COMPONENT

INTRODUCTION:

The objectives of the first phase for this component of the study, as outlined in the attached working paper, have been partially met. A summary of an interim report containing the outcomes is attached. A detailed report is being prepared

There have been the following developments at KSC regarding the application of the VDES in process 310:

1 - The current VDES (developed by Lockheed) is being reconsidered.
2 - NASA is interested in shifting to a microcomputer based VDES.
3 - NASA is interested in exploring new areas of applications for the VDESs.
4 - With the gradual shift at KSC to computer based systems, NASA is interested in investigating the interface between the VDESs and the overall computer system at KSC.

Based on these developments, the use of the outcome of phase I of this component (Training and Implementation Strategies) which was the logical and planned activity for phase II of this component will be differed to a later phase and after successful demonstration of a working application.

The purpose of this working paper is to outline the objective, procedure, and expected outcome for phase II of this component of the study.

OBJECTIVE:

To study the feasibility of microcomputer based VDES compatible with KSC environment. The vehicle for such study is a laboratory experiment for a selected KSC application.

PROCEDURE:

- New team members become familiar with the technology of voice synthesis and recognition, NASA-KSC environment and previous phase effort.

- Acquire the hardware and setup a laboratory.

- Select a well suited application (P-310 is a good candidate since much information/ data is available for such process).

- Design and carry on a laboratory experiment of the selected KSC application. This may require develop/ modify the necessary software.

- Study other application for the VDES compatible with KSC environment and need.

- Document experiment results, findings, ...etc in a technical report.

OUTCOME:

1) Technical report documenting the findings of this phase (experiment and system performance evaluation, KSC potential applications, problems associated with interfacing with KSC system).

UCF TEAM INVOLVED:

Hosni, Swart, Tamin, K. Cole

UNIVERSITY OF CENTRAL FLORIDA
INDUSTRIAL ENGINEERING PROJECT
UCF/KSC COOPERATIVE AGREEMENT

WORKING PAPER FOR PHASE II - SPRING 1990

WORKSTAND DESIGN COMPONENT

INTRODUCTION:

The objectives of the first phase for this component of the study, as outlined in the attached working paper, have been met. An interim report containing the outcomes is attached.

The purpose of this working paper is to outline the objective, procedure, and expected outcome for this phase of the study.

OBJECTIVE:

To build a prototype for one of the alternatives designed in the first phase.

PROCEDURE:

- Refine and finalize a working design. Considerations should be given to job analysis (requirement) and application restrictions as outlined in Phase I report.
- Specify and order standard parts, and specify and supervise any fabricated parts.
- Assemble a prototype in the IE laboratory.
- Conduct a laboratory evaluation for the prototype using simulated tasks. Modify\ whenever feasible.
- Prepare the prototype for "on site" application.
- Document design, findings, etc., in a technical report.

OUTCOME:

1) Prototype for an overhead working stand/facility.

2) Technical report documenting the findings of this phase (design and evaluation.)

UCF TEAM INVOLVED:

Hosni, Lee, Lisa Guthrie.

II. Phase I outcome:

1. 3-Year Proposal to NASA/KSC
2. Cavity Digitization Interim report
3. Workstand Design Interim report
4. Voice Data Entry for P-310 - Training and Implementation Strategy Interim report
5. Technical Papers and Conference Presentations

   5.1 Tally
   5.2 Sample papers

6. Proposals to Other funding agencies

   6.1 FHTIC Proposal
   6.2 Florida Space Grant Program

7. Project Outcome Presentation

3-Year Proposal to NASA/KSC

APPENDIX A-6

PRODUCTIVITY IMPROVEMENT TECHNIQUES

DR. YASSER A. HOSNI
DR. WILLIAM W. SWART

PRODUCTIVITY IMPROVEMENT TECHNIQUES

1. INTRODUCTION TO THE GENERAL RESEARCH AREA

Thermal Protection System (TPS) accounts for a substantial portion of the cost and time of shuttle processing at Kennedy Space Center (KSC). The use of industrial engineering (IE) principles in the development of new tile processing methods should decrease cost while increasing the reliability and efficiency of operations.

The objective of this research plan is to increase productivity and reduce labor intensiveness in the TPS processing operations through automation and the use of new technologies such as voice recognition, photomechanics, and knowledge based systems. Aspects of the study include the integration of TAS equipment in an ergonomically designed work stations, man-machine interfaces, and the human engineering aspects associated with the Tile Automation System.

The outcome of this project should benefit similar operations common to the industrial community at large.

Delays, inaccuracies, deviations, and irregularities may add significantly to the cost of TPS processing at KSC. Operator fatigue, work dissatisfaction, personal injuries, and damage to equipment and the orbiter can make these costs increase substantially and cause longer delays. Due to the complexity of tile processing operations and the high degree of labor intensiveness, especially between missions requiring large number of tile repairs and replacements, tile operations require extensive man hours to accomplish. In addition, the tile technicians frequently operate from uncomfortable positions during processing. TPS activities will continue to be a limiting factor in determining future flight rates due to the magnitude and the complexity of the tasks required.

Initial assessment of tile processing operations at KSC shows promising areas for improvement especially those related to the introduction of new technologies and human performance. Such improvements should reduce cost while increasing the reliability and efficiency of TPS operations. The impact of such improvements on the overall system and the effect of automation on productivity and operator's performance and morale should be studied from the human factors point of view. Of special importance in the handling of the transition period from manual to automated is the design and implementation of an efficient training strategy that will guarantee the benefits of automation.

TPS operations are common to the "project" type of production systems, where limited units are produced (usually one unit), and where operations are unique and nonstandard. Examples of such operations are found in the avionic industries, shipyards, as well as the repair and maintenance jobs. Research is needed to support operations of this type and any innovative techniques which may result from this project should have a positive impact on these industries. Outcome of the project may be propagated to other industries through NASA regular publications such as periodical NASA Tech briefs and presentations in related conferences.

2. DESCRIPTION OF SELECTED RESEARCH OBJECTIVES

The overall objective of this research project is to increase the productivity and quality of the TPS. The vehicle for achieving such objective is to apply industrial engineering methods and techniques in the design and implementation of the Tile Automation System (TAS) currently under consideration at KSC. THe eventual success of TAS depends on its acceptance by the user. Therefore, the consideration of tile technicians

in the implementation of TAS is critical. Application of sound industrial engineering (IE) principles to new tile processing methods will enhance the quality and productivity, thereby demonstrating applicability to other areas of shuttle operations.

Preliminary work is being conducted in the Summer of 1989 where the current effort is concentrated on resolving problems associated with the use of the voice data entry system by the floor technicians and the study of tile technician's productivity and work environment.

3. ANTICIPATED RESEARCH METHODOLOGIES

Because of the wide range of potential improvements, the plan of this project calls for its implementation during three consecutive one-year phases. Following are the objectives and methodologies expected for each phase.

Phase I:

1. Continue testing and validation of speech recognition system developed by the research team and the NASA subcontractors. The initial system is currently being developed and technicians will be formally trained on its use in the shuttle processing environment. Problems associated with remote communication to central computer will be addressed and standardized.
2. Study the workers "acceptability" to the automation processes from the productivity point of view. Possible ideas are the involvement of tile processing teams in the systems design and its implementation. Techniques such as the "quality circles" may be applied in soliciting direct labor input and participation.

3. A study will be conducted to recommend "job enrichment" measures for tile technicians compatible with the automation effort. Such study will include current and former tile technicians. The outcome of the study will be in the form of specific recommendations and methodologies which should increase the retention of tile processing technicians and increase job satisfaction. (Preliminary effort of such study starts in summer of 1989).
4. Develop a prototype for the tile work station. Such prototype will be based on the design developed in the preliminary summer 1989 studies. This design considers, ergonomics and operator positioning, TAS interfaces, mobility, flexibility, maintenance, NASA standards and produceability of such stations for similar operations.

Phase II:

1. Continue the support of the voice recognition system and its implementation on a larger scale. This may include studies for propagating the system to other systems in addition to the TPS.
2. Assess the productivity gain in the tile processing as a result of the TAS. This may require conducting comparative time analysis for non-standard operations. The study will also assess the cost effectiveness of the various elements of the TAS.
3. Study the feasibility of incorporating the use of photomechanics in the tile processing. The study would be both technical and economical. Photomechanics is a time saving technology which should have an impact on the productivity of manufacturing damaged tile. The technical study will address the state of the art of available equipment while the economical study will concentrate on the cost analysis of

photomechanics vs. manual methods. The study will include applications to other shuttle systems which may benefit from the photomechanics technology. Possible candidates are the panel inspection, contour and curvature measurement.

Phase III:

1. Develop a knowledge based inspection and tile damage assessment system. Currently the inspection process is human dependent. Damage assessment and estimation of processing time and cost is based on work study - mainly due to the randomness associated with the tile damage and the limited number of shuttle missions. This results in some duplication of effort as well as inaccuracies which propagates to the scheduling system. The idea of the proposed system is to classify the damage based on a number of criteria (processing time, resources, requirements, ... etc). Data correlation - with the increase of shuttle missions - will constitute the system knowledge base. Once a tile damage is classified, the system will estimate processing time, degree of automation, material, equipment, labor skill and any other processing requirement. A cost component may estimate the processing cost. A by-product of the system will be the identification of critical areas-heavily damaged-for future mission of the vehicle.
2. Study the feasibility of incorporating other data collection in the laser step and gap sensor currently under study at KSC. Possible candidate for such data is an automatic tile identification mechanism. Consideration will be given to coding "material" and its protection from the intense heat at orbiter entry time, as well as compatibility of any developed module to the overall computer based systems at KSC.

3. Integrating and documenting TAS modules and propagating them to other industries whenever feasible.

4. EXPECTED RESEARCH RESULTS/OUTCOMES:

1. Technical reports summarizing the findings and results will be produced at the end of each phase. The technical aspects of the reports will be formulated as technical papers. It is expected that at least four technical papers will result from this project dealing with the following areas:
    1. The use of voice synthesis and recognition in manufacturing.
    2. Photomechanics for tool pathing for production systems.
    3. Productivity enhancement through high technology applications.
    4. Ergonomically workstand design for overhead operations.
    5. Man machine interface for new technology applications on shop floor.
2. Prototyping of two person workstation for overhead operations.
3. The design and development of "seeds" for two computer based system for the following:
    1. cost and time estimation for nonstandard operation (application will be on the case of tile damage).
    2. Productivity improvement control system based on the "quality circle" concept.
4. Summaries for project outcomes for NASA tech briefs publications.

5. EXPECTED COLLABORATIVE ARRANGEMENTS

The close vicinity of UCF to KSC makes it ideal to have frequent visits. It is expected that considerable time will be spent by the PI's

and graduate students at KSC to collect data, analyze the problems and perform mutual inspections. The KSC investigators are expected to spend some time in the UCF laboratories to help set up laboratory tests and simulate conditions as close as possible to that in site. The study results will be routinely shared and discussed and the process will be updated routinely. UCF will provide the "science" while KSC will provide the operational involvement to solve some of the most demanding and challenging problems of labor intensive operations at KSC. The Ames Research Center human factors laboratory research staff will be part of the KSC/UCF applications research effort and will assist where appropriate, evaluate research results, jointly prepare research papers, and assure that the results are shared with the NASA, DOD, NSF and other agencies with which they work in the human factors area.

Productivity Improvement Techniques

Schedule - 3 yr. proposal

Phase I Activity:

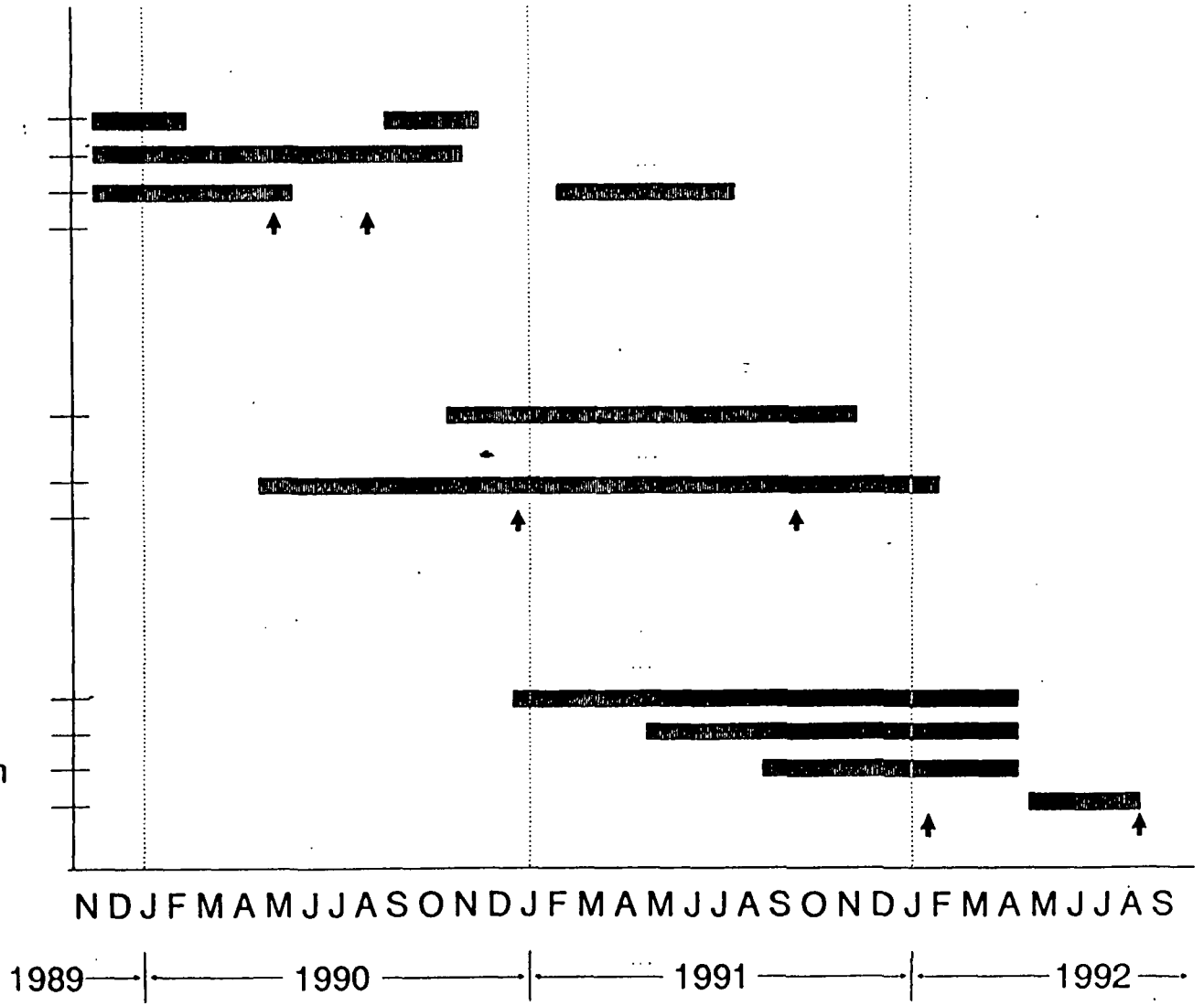
- Voice Entry System
- Productivity study
- Work station prototyping
- Reporting

Phase II Activity:

- Productivity Gain Study assesment
- Photomechanics
- Reporting

Phase III Activity:

- Resource predictor
- Data collection mechanism
- Intergeration & Propagation
- Reporting



Cavity Digitization

Interim Report

NON-CONTACT, THREE-DIMENSIONAL OBJECT DIGITIZING SYSTEMS

BY

DANIEL K. NASSER
B.S.E.E., University of Florida, 1986

RESEARCH REPORT

Submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Graduate Studies Program
of the College of Engineering
University of Central Florida
Orlando, Florida

Fall Term
1989

ABSTRACT

The new field of non-contact 3-D object digitization has many applications in industry. The state of the art in technology uses electro-optic measurement techniques such as laser based triangulation and phase measurement projection Moire profilometry, for obtaining a non-contact, X-Y-Z coordinate representation of an object. This paper presents an overview of the theories of operation, as well as an analysis of a basic system. In a separate component, the performance issues, as well as potential applications within computer integrated manufacturing (CIM), are discussed. A market study for commercially available systems shows the technical specifications and capabilities, of the state of the art in 3-D object coordinate digitizing technology. A comparison of the different systems and approaches is presented as well.

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CHAPTER 1

INTRODUCTION

Three-dimensional (3-D) object digitization is the measuring of the coordinates of a number of discrete points on an object's surface. Automated measurement can be done by traditional contact measurement, such as using a coordinate measuring machine (CMM). Many industrial applications require the use of electro-optical techniques for measurement, which offer higher speed measurement (hundreds times faster), and a higher density of measured points, giving much higher resolution for intricate objects. Also, electro-optic measurement methods offer a non-contact digitization that does not deform the measured object.

The precision measurement of a 3-D solid involves the manipulation of large amounts of data. This is mainly due to the measurement of many points on the object's surface. Techniques have been available for decades that provide 3-D information of objects and surfaces. Limitations are that the analysis is done by human observation, rather than by computer processing, and that an automatic and complete synthesis of 3-D objects is not possible. The advancement of computers, and their interfacing with optical devices, has led

to the advancement of the performance and applicability of 3-D digitizing systems. Recent improvements in electro-optic detectors make computer based measurement using light, quick and automated. Fast and inexpensive data processing by today's computers make digitizers a powerful tool for many industries.

Although this technology has a wide range of applications in many fields, this paper focuses on the use of 3-D digitizers on computer integrated manufacturing (CIM). Three-dimensional digitizers contribute directly to the goal of CIM, which is in achieving a synergism with existing technologies. Digitizers are input devices that interface the real world to the information system of an industrial environment. In many applications, this feedback information will correct many CIM functions and improve the quality of a process. Figure 1.1 shows a CIM information flow, and possible 3-D digitizer implementations. CAD functions can be automated when a physical model is present. The accuracy of a CAD/CAM to CNC system can be checked by comparing the actual measurement of a manufactured part versus the original design parameters. Digitization is achieved so fast that real time quality inspection for 3-D parts can be achieved. For example, digitization of molded parts many times can be done in a shorter time than the actual manufacturing cycle time. This information can lead to in-line process control feedback to optimize manufacturing parameters. Computerized equipment

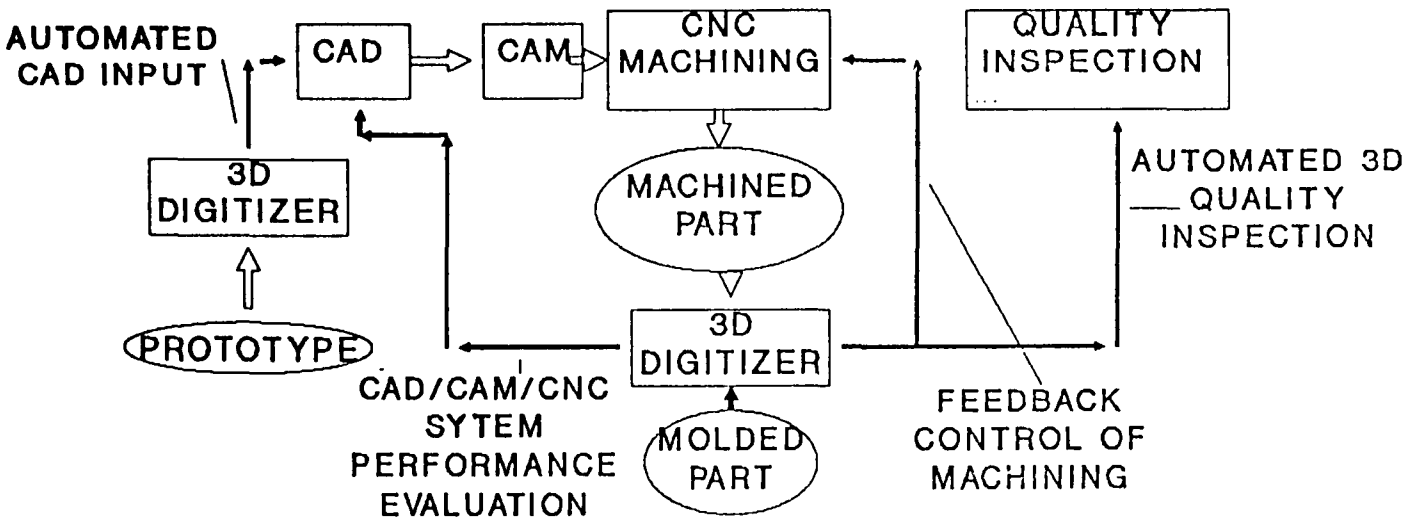

Figure 1.1. Possible Implementations for 3D Digitizers within a CIM Environment.

equipped with 3-D rangers can obtain feedback to learn more about their environment. Commercially available digitizing systems can be retrofitted to a CNC machine, and replication functions can be made automatic. This automates the CNC programming effort as well.

Current efforts in achieving long range measurement are being implemented in the fields of robotics and guidance systems. Two-dimensional vision systems have been difficult to implement because they require much interpretation processing. They only obtain a reflected light value for discrete points on a surface, and this data is dependent on the uneven reflectivity properties of an object. Digitizers provide a physical 3-D description, which is a collection of X-Y-Z points for the viewed surface. This information can readily be useful for end effector tracking, critical in high precision robotic and machining applications.

This paper presents the state of the art in non-contact 3-D measurement systems that can obtain an X-Y-Z description of an object's surface. The most widely used techniques for achieving 3-D measurement are presented. Laser triangulation and Moire contouring systems have advanced to the point that relatively low-cost systems can be implemented effectively in a number of industrial environments. A market summary provides an evaluation of the state of the art in commercially available 3-D surface mapping systems. The functions and performance of the basic system components are presented. A

low cost 1-axis positioning system is proposed that automates the positioning of a digitizer to achieve complete surface maps of both concave and convex objects. The mechanics of the system are presented. A comparison of digitizing systems and approaches along with conclusions is presented as well.

The reader of this report should be able to learn more about the operation, limitations and capabilities of 3-D digitizing systems, and become knowledgeable of the state of the art in commercially available equipment.

CHAPTER 2

THEORIES OF OPERATION

We present the background theory of two methods used in commercially available systems that produce an X-Y-Z representation of an object. The geometries of the system are presented, and the equations used at producing the coordinates of reflected points on an object's surface are derived.

Laser-Based Triangulation

Figure 2.1 shows the basic configuration of a 3-D laser ranging device. A laser light source produces a narrow light beam which is scanned across the object to be measured through the use of a two-dimensional mirror scanner. A lens collects the reflected beam and is displayed on an electro-optical position sensor. The linear position of the reflected light, along with the angles of deflection of the scanner, determines the 3-D coordinates of a point on the object's surface. Following is an explanation of the geometry used to arrive at the X-Y-Z representation of the object.

Triangulation Geometry

Coordinate measurement is calculated by means of trigonometry of the light beam. Figure 2.2 shows a beam of

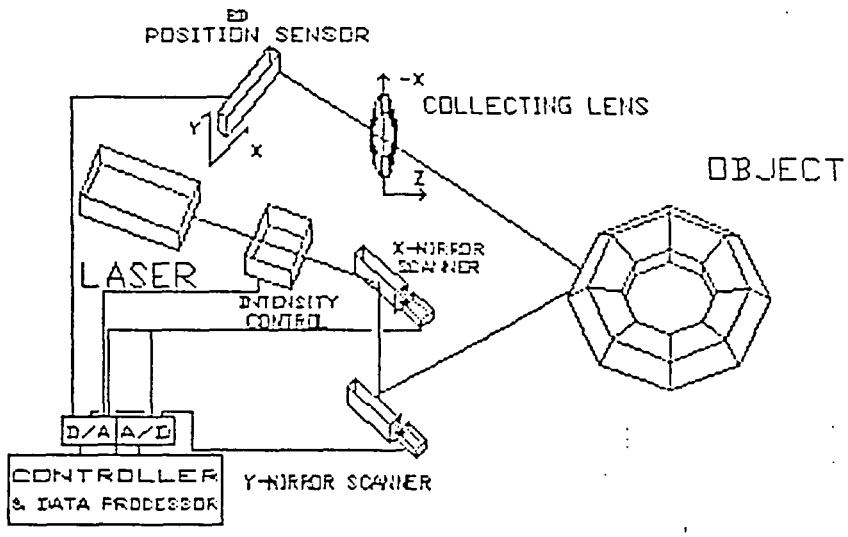

Figure 2.1. Typical 3D Laser Ranging System.

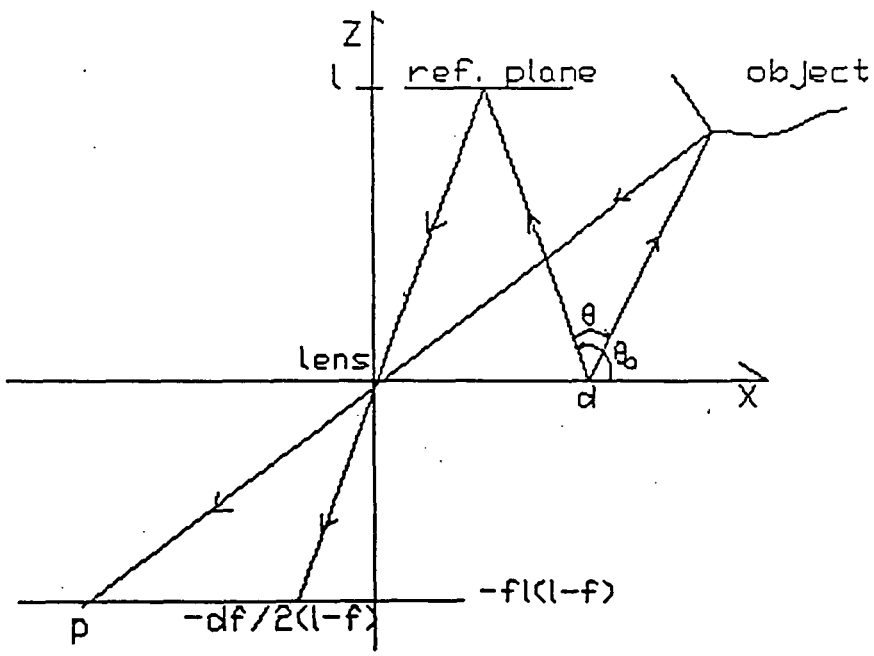

Figure 2.2. Basic Triangulation Geometry.

light originating at a point d on the X-axis at an angle theta with respect to the X-axis. The beam is reflected at a reference point (d/2,1) (used for calibrating purposes) and enters the collecting lens whose center is at the origin. Using the basic lens equation, the lens focuses the reflected light at a location z=-fl/(l-f), where the position sensor is located. We find that the image position for the reference point is -df/2(l-f). As shown in Figure 2.2, d, l, and f are known and are, respectively, the distance between the scanner axis of rotation and the principal point of the lens, the distance between the common axis of projection and detection (0,-d,0) and the reference point, and the focal length of the collecting lens. The laser light beam direction is changed by means of a mirror scanner and is now projected with an angle ($\theta+\theta o$). This will force the reflection of the beam to a new position (x,z) on the object to be measured. The beam will then change its position on the position detector to a new point p. Trigonometry and lens equations lead to equations that give the unknown x and z values for the point were the laser beam has reflected, in terms of θ,p,l,f,d:

$$x = d.p\left[p+\frac{f.l(2l.\tan\theta+d)}{(1-f)(d.\tan\theta-2l)}\right]^{-1} \qquad (1)$$

$$y = -d\left[\frac{p(1-f)}{f.l} + \frac{2l.\tan\theta + d}{d.\tan\theta - 2l}\right]^{-1} \qquad (2)$$

To be a true 3-D measuring device, we need to scan the object at varying y values. Normally, this is obtained by the addition of a y-axis mirror scanner and an extra axis of detection for the detector. The 3-D geometry will be shown using a synchronized scanning approach which only uses a 1-axis detector for 3-D measurements.

Synchronized Scanning

Synchronized scanning offers higher accuracy and a more compact geometry (Rioux, 1984). Figure 2.3 shows that for increased field of view, the detector size increases. This imposes a compromise between field of view and height resolution. If the detector lens followed the laser beam by rotating in synchronization with the x-axis scanner, the detector area will mostly be used for determining height (see Figure 2.4). Field of view and height resolution therefore become almost independent of each other. The new formula for the position becomes,

$$p = p' + \frac{f.l.\tan\theta}{l-f}\left[1 - \frac{p'(1-f).\tan\theta}{f.l}\right]^{-1} \qquad (3)$$

Figure 2.5 shows the addition of a y-axis mirror scanner that deflects the incoming and outgoing light beams to change the

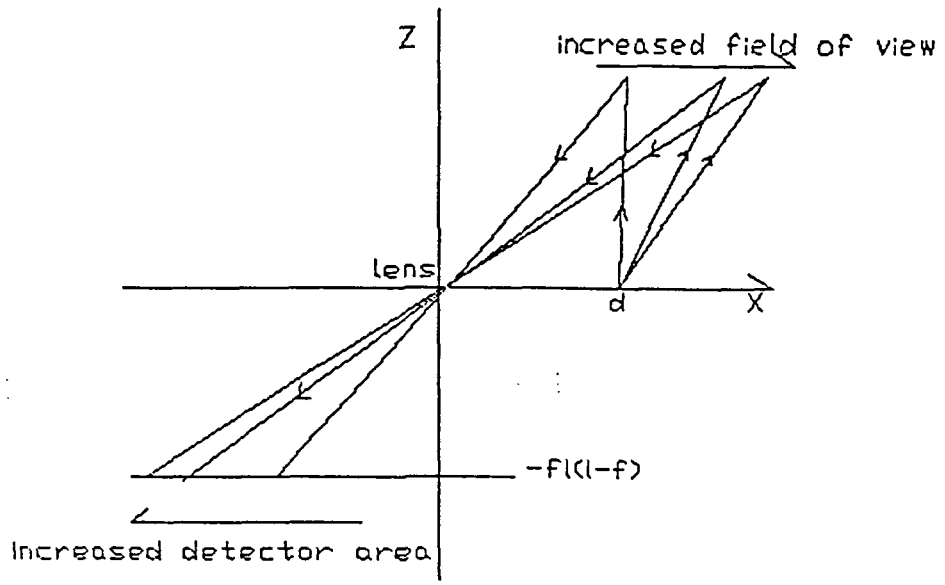

Figure 2.3. Effect of Increased Field of View on Detector Area.

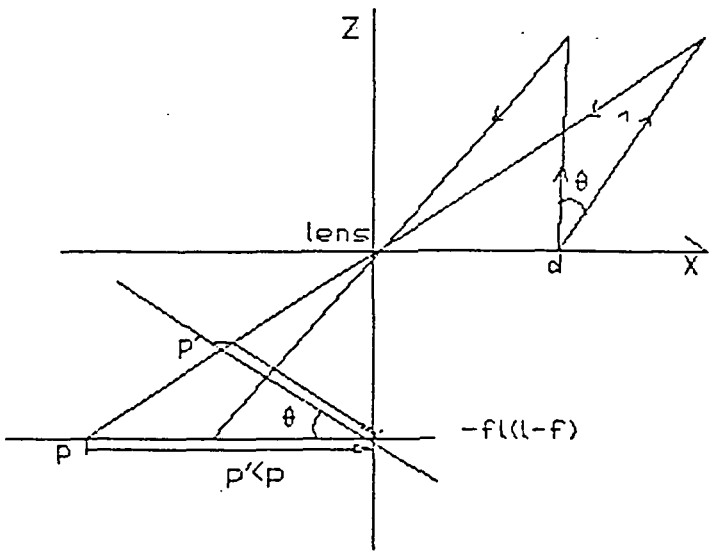

Figure 2.4. Synchronization Effects on Detector Area.

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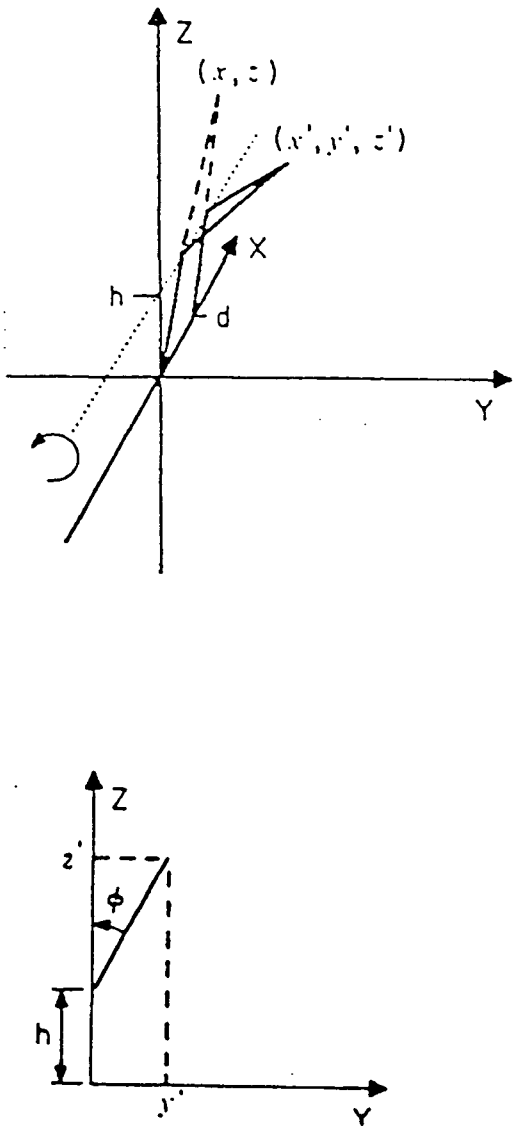

Figure 2.5. Addition of a Second Mirror for Y-Axis Measurement.

y-axis value. The synchronization is achieved because both the incoming and outgoing light beams are reflected the same amount. This mirror is located at a height h above the x-axis on the x-z plane. The resulting geometry modifies equations (1), (2), and leads to complete expressions that describe the location of the measured point in 3-D space.

$$xi = d.p\left[p + \frac{fl}{(1-f)a}\right]^{-1}, \qquad (4)$$

$$yi = [h - a(xi - d)] \sin \phi, \qquad (5)$$

$$zi = h + ([-h + a(xi - d)]\cos \phi), \qquad (6)$$

$$a = \frac{d.\tan\theta - 2l}{2l.\tan\theta + d} \quad . \qquad (7)$$

A collection of xi, yi, zi values makes up the 3-D view representation for a given object. The scanner maps out a two-dimensional area by changing the values θ and ϕ of the scanning mirrors similar to the raster scan of a CRT. The sampling density can be controlled by reading the position sensor at given step increments for θ & ϕ. The scan length and width are given by the maximum deflection for θ and ϕ and the distance the scanner is away from the viewing plane. It is interesting to note that only a linear detector is needed for the synchronized scanning approach, due to the synchronizing effects of the y-axis mirror scanner which deflects both the outgoing and incoming light beam into a common linear dimension.

The following section explains the Phase Measurement Projection Moire Profilometry method used for obtaining an X-Y-Z representation of an object's surface.

Phase Measurement Projection Moire Profilometry

Moire contouring techniques have been used widely in 3-D measurement. The latest interests have been in automatic measurement based on computer data processing. We will discuss a method for obtaining an X-Y-Z representation of an object by projecting equally spaced light fringes onto that object (Takeda,1983). A 2-D picture is captured by a T.V. camera and digitized into a computer. The phase shift of the light fringes on this image leads to the calculation of height values for every point. In the next section, we will attempt to describe the geometry used for a typical surface mapping application.

Crossed Optical Axes Geometry

The Crossed Optical Axes geometry is shown in Figure 2.6. The projector and detector axes are crossed at a reference ficticious plane R at point O. This plane will serve as a reference for height measurement, i.e., for all points on R, h(xi,yi) = 0. The grating image has its lines normal to the plane of the figure. The height of the object, relative to R, is calculated from the distance CD. Since triangle Ep, H, Ec is equivalent to triangle C, H, D then,

$$CD = -d.h(xi,yi) / (lo - h(xi,yi)), \qquad (8)$$

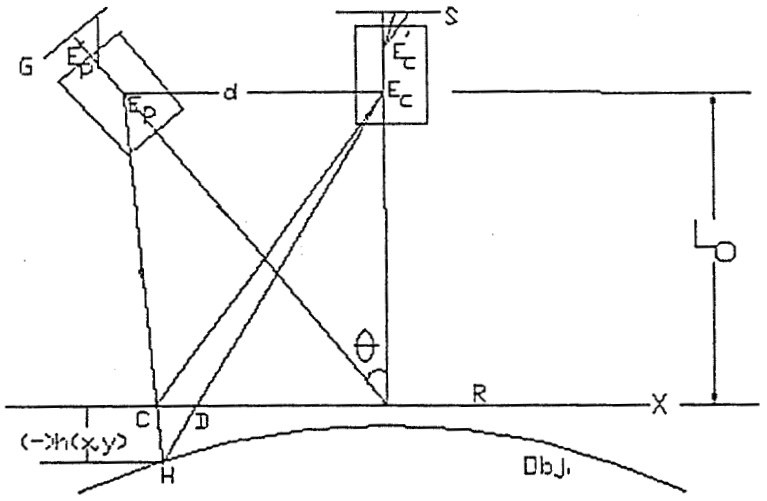

Figure 2.6. Crossed Optical Axis Geometry.

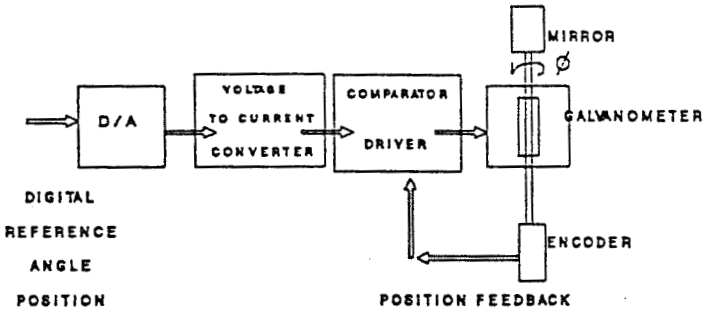

Figure 3.1. Typical Scanner Control Information Flow.

$$h(x,y) = CD.lo / (CD - d), \quad (9)$$

where lo is the distance the projector and detector are away from plane R, and d is the separation between the center of the projector and detector. To obtain CD, we need to process the two-dimensional light information digitized into the processor. It can be proven that,

$$\Delta\phi(xi,yi) = 2\pi fo\ CD, \quad (10)$$

where fo is the fundamental frequency of the observed grating image. Substituting Eq. (8) into (10) we obtain

$$h(xi,yi) = lo.\Delta\phi(xi,yi) / [\Delta\phi(xi,yi) - 2\pi fo.d] \quad (11)$$

The problem is to obtain the phase shift to obtain the third dimension z= h(xi,yi). This information is obtained from the deformed grating image as viewed by the camera. The frame capture system obtains a light measurement value for points as seen on plane R. Using Fourier transform methods, the value of $\Delta\phi(xi,yi)$ is computed using the light intensity values stored in the memory of the interpreter data processor. This method is used, since the amplitude of the light signal (dependent on uneven reflectivity) needs to be separated from the phase shift component. Once the height (z-value) is calculated for every point on plane R, an output file is generated which is a collection of 3-D points of the form [xi,yi,h(xi,yi)].

Chapter 3 breaks down the systems that use the methods described in this chapter into the basic components. This will give the reader a better understanding of the functioning

of an actual system and how the components determine total system performance.

CHAPTER 3

SYSTEMS' CHARACTERISTICS

The basic system components of a digitizing system are explained. The second section presents an application example of a low cost positioning system (an integral part of the digitizing system). Through this application, guidelines to construct a positioning system are presented.

Basic System Components

We can classify the components of electro-optical surface mapping systems into light source, scanner, detector, positioner, and control and interpreter data processor.

Light Sources

Lasers. Used mainly in active triangulation systems, lasers can also be used to generate a series of fringes for Moire contouring. The main types of lasers used for most imaging applications are HeNe and solid state diode lasers. These are chosen because the desirable characteristics of compactness and low cost are present. Most systems use laser power that does not exceed 10 mW. Lasers are chosen in triangulation systems because of their ability to produce a narrow beam of high intensity light with a very small divergence angle. This leads to more resolution and more

accuracy. The high intensity is needed since the amount of light reflected by the object and captured by the detector is a very small fraction of the original projected light intensity.

Moire Projector. Used in Moire contouring, the Moire projector is composed of a light source, a grating, and a lens system. The light is allowed to pass through the grating and is projected by means of the focusing lens. The light pattern that is mostly used in Moire contouring systems, is composed of straight line fringes spaced equidistantly apart with a fundamental frequency fo. It is important to note that most projectors are non-telecentric, meaning that the resulting image rays are not beamed parallel. This will cause a phase variation of the fringes (increasing as the fringes move away from the projector) if they are projected at an angle onto the object. This factor must be taken into account when calculating height differences on objects surfaces. The pitch of the line gratings can be changed in order to satisfy the right degree of measurement sensitivity, because it is the phase shift of the fringes on the object that provide the height information. If the surface slope varies excessively, discontinuities will occur when the phase shift reaches 2π, and height information may be lost. A small pitch will lead to higher accuracy, but will also give rise to more discontinuities as the slope of the object's surface increases. The fringes have to be equally spaced, and the

lens projection has to be even over the entire projected surface so that the Fourier transform models are exact.

Scanners

Used in laser based systems, the scanners are a series of deflecting mirrors whose position is controlled by electro-mechanical means. This control, done by the system controller through digital to analog converters, accurately changes the position of Θ and ϕ, to map out a surface at a given step and speed. Galvanometer scanners are usually found in 3-D surface mapping systems, which change mirror position linearly for a given current (see Figure 3.1). A digital signal sent from the controller enters the digital to analog converter, producing a voltage proportional to the digital signal value. A current is then produced proportional to the D/A output voltage, through the use of a voltage to current converter, and thus the position of the galvanometer and mirror assembly is linear in relation to the digital control value. For high speed scanning, other methods such as piezo-electric actuators and acousto-optic deflectors are used as well. Also employed are polygonal mirror scanners which provide a higher speed scanning (see Figure 3.2). By having multiple mirrors, synchronized geometries can be attained which lead to an efficient and compact system. These mirrors rotate at high speeds. Only in one dimension is the scanner needed to be fast, since the other axis scanner changes position when all

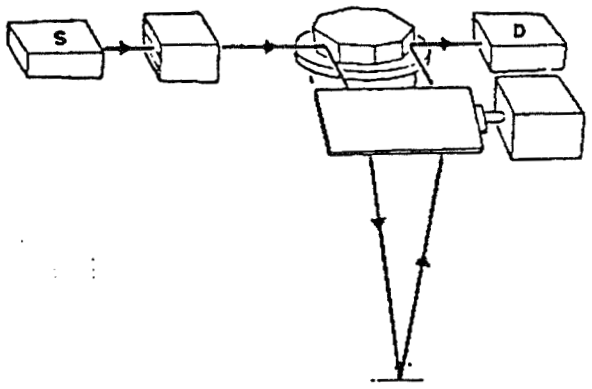

Figure 3.2 Polygonal Mirror Configuration for Laser Digitizer.

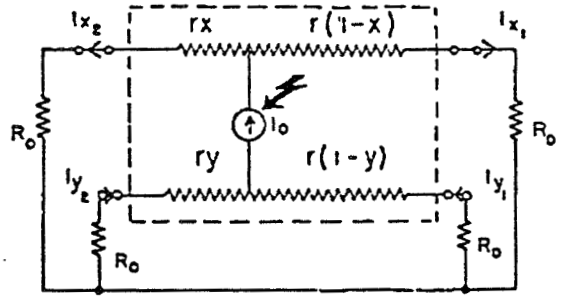

Figure 3.3. Equivalent Circuit for Analog Position Sensor.

the steps are completed for the other axis. Therefore, a combination of polygonal and low inertia galvanometer scanners are used frequently. The main performance requirements for scanners are stepping time, time at which the scanner is stable at a new position, and mechanical scan angle accuracy and repeatability, which directly affects the measurement error. Also, many scanners are limited to the maximum angle of deflection, which in turn may limit the field of view. The scan length and width are given by

$$\text{scan length} = \tan(\theta\text{max}).(d+s) \qquad (12)$$

$$\text{scan width} = \tan(\phi\text{max}).s \qquad (13)$$

where d is the distance between the x and y axis scanners, s is the standoff of the digitizer, and Omax and omax are the maximum angles of deflection of each scanner.

Detectors

Laser based systems need to detect position shifts in one and two dimensions [see Equation (3)] to determine X,Y,Z coordinate information. This detection must be done at high speeds and converted to a digital signal for the computer to determine a point measurement. There are several types of detectors used in 3-D gauging applications: 1 and 2 axis analog position sensors, photodetector linear arrays and ccd matrix arrays.

Analog Position Sensors. Mainly used for high speed scanning, APSs produce two currents per axis that give information of

position. Figure 3.3 shows a simplified equivalent circuit of the position sensor chip. It is constructed of two layers of homogeneous resistance network. Current sources Ix and Iy emerge at the position where a spot of light is projected. For (x,y)/0<=x<=1, 0<=y<=1 (light beam position on chip), formulas are arrived at through measurement of the currents shown in Figure 3.3:

$$px = \frac{Ix1 - Ix2}{Ix1 + Ix2}, \qquad (14)$$

$$py = \frac{Iy1 - Iy2}{Iy1 + Iy2}. \qquad (15)$$

The load resistance Ro is a current to voltage converter usually connected to an analog to digital converter for computer position calculations. A video image can also be reconstructed by a reflectance map obtained from the intensity value Io = Ix + Iy, given by [xi,yi,Io(xi,yi)].

Photodetector Linear Arrays. As the name describes, these detectors are composed of a line of individual digital photodetectors. When a light beam strikes a cell, a high signal is produced and the pattern of the array is shift registered to the interpreter processor, where the position is calculated. These detectors offer high resolution with some arrays having 4096 elements. Speed is slightly slower as compared to APSs.

Ccd Matrix Arrays. Charge coupled devices are used in Moire contouring systems through the use of a T.V. camera. A high precision, non-distorting lens system is needed since it affects directly the accuracy of the system. High resolution cameras may have up to 4096x4096 elements obtaining a light intensity on a grey scale from 0 to 255 for every point. These light intensity values are used to calculate the phase shift and the height for every point on the x-y plane which in turn corresponds to a pixel on the ccd array. A conversion is required that translates the location on the ccd array to the X-Y location on plane R. Ccd arrays can also be used in laser triangulation systems, but the speed is much slower (approximately 10Khz).

Control and Interpreter Data Processor

For most applications, the data processing of a 3-D digitizer can be divided into the control section and the interpreter section. The control processor is in charge of obtaining the X-Y-Z surface mapping data. It interfaces directly with the system's light source, scanner, and the detector to obtain the geometry parameters (θ,ϕ,p), for laser based systems, or the light intensity values g(x,y) for Moire profilometry systems. In laser based systems, if coordinate calculations are to be done in real time, the bandwidth of the scanner and position measurement has to be greater than the digitizing speed. Commercially available systems can obtain

a speed of 10,000 points/sec; the total time for point measurement becomes 100 usec. Therefore, very fast processing times are required for the control processor. In Moire based systems, a 2-D image digitizing board connected to a T.V. camera can obtain a frame very quickly. It is then up to the transformation algorithms to determine the height for every point on the viewed plane. Some systems using personal computers can calculate 2500 point coordinates per second.

Once the digitization is complete, the interpreter data processor stores the surface map. It can then manipulate the data for graphical output to a screen or plotter, or it can interface and feed points to a CAD system. If view integration is needed, the processor can transform the points into a compatible coordinate system. The amounts of information processing and storage are very high. For example if we want to digitize a 4x4" area with points at every .01", approximately a 512x512 map is needed. If we represent the measurement with 2 bytes for each dimension coordinate (a resolution of 1 in 65000), then the amount of storage required is 1.57 Mb. We can multiply this number by the amount of views necessary to digitize the complete object. It is no wonder then that digitizing systems have not been widely implemented before the computer revolution. Today's personal computer offers high speed processing and inexpensive data storage capability. This factor will allow the cost reduction of digitizing systems.

Positioning Systems

Positioning devices are an integral part of the 3-D gauging system, although there are many instances when only a fixed position for the gauger is needed. Nevertheless, it is essential that the digitizer be mounted on a fixed structure that does not move or vibrate, because any movements during a scan will cause measurement errors proportional to the magnitude of the movement vector. A fixed positioner is needed only when the following conditions are met. A surface mapping of an object is needed, not a complete 3-D representation of an object. The field of view and depth of field are larger than the object, and larger than the height of the object respectively. There are no points on the surface of the object such that the slope exceeds the limit for that measuring device. There also are no shadowing effects, i.e., a portion of the object cannot be seen by the detector because another part of the object is in the way. It is because these conditions are rarely met that a positioning system is needed. Three-dimensional objects need an integration of surface maps taken at different positions and angles to obtain a whole 3-D representation of the surface contour. In order for the surface maps to be integrated, the position of the gauger has to be known, since all the points obtained from a surface scan are referenced to the location of the scanner. The accuracy of the positioning system has to be much greater than the digitizer accuracy because both

these errors are added. Also, it is very convenient for the positioner to be motorized to increase the digitizing speed. Some controllers allow for the automatic input of position information from the positioning system to automate the view integration process. For these and many other reasons, coordinate measuring machines are used for positioning the gauger. Many times, a CMM increases the cost of the system excessively. For many applications where the general size and shape of the objects are known, much simpler positioning systems can be used. Both linear and rotary systems can be used. The next section of this chapter presents an example application using only 1-axis for positioning of a digitizer to obtain complete views of both concave and convex 3-D objects.

Applications: A Low Cost 1 Axis Positioning System

Figure 3.4 shows a 1-axis rotary positioning system composed of a motorized rotary table placed above the X-Y measuring plane with rotation about the Z- axis as shown. A method for selection of optimum positioning parameters for the digitizing set-up is presented. The integration transformations are arrived at for this geometry. A conversion process is needed to integrate the points scanned from many views referenced to a different digitizer coordinate location, to a world coordinate system, so that view integration is possible.

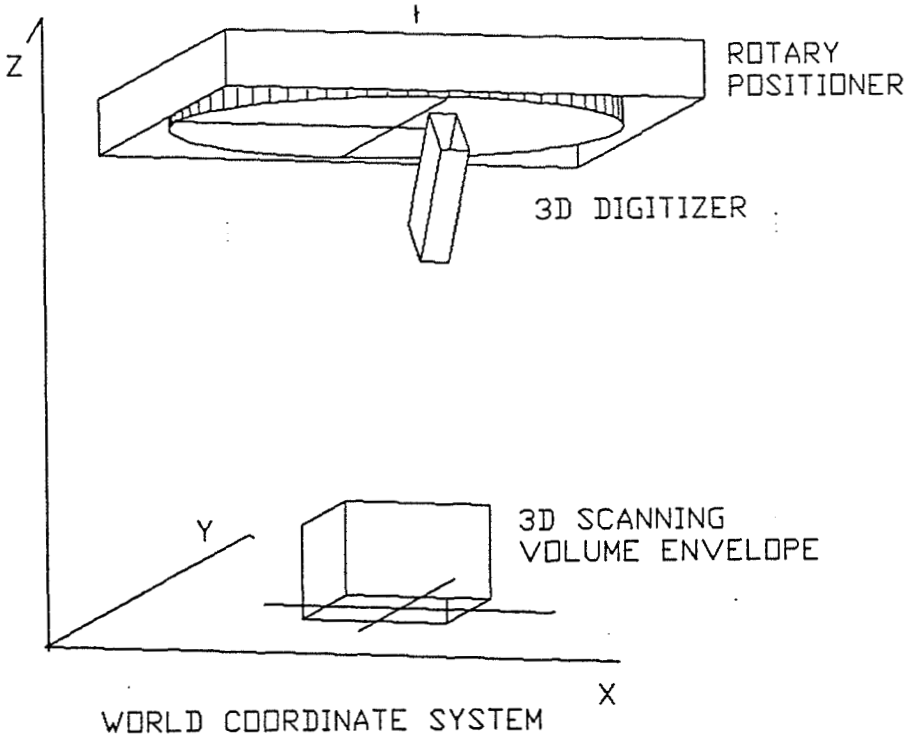

Figure 3.4. 1-Axis Rotary Positioning System.

Positioning Optimization

The objective is to calculate the construction geometry parameters for this set-up that will lead to a complete and optimum digitization of a 3-D object. Very predominant in industrial environments is information regarding the general size of the objects to be measured. Therefore, an object volume is created and used to calculate the geometries. As well as sensory data, it can be seen that underlying, a priori information is another component that improves perception.

Consider a 3-D volume envelope shown in Figure 3.5 that is to contain the inspected part. The centroid position vector is given by $\vec{C}$,

$$\vec{C} = 1/2\ \vec{i} + 1/2\ \vec{j} + ho\ \vec{k}\ . \qquad (16)$$

The center of the rotary table is placed above the centroid of the volume space at a height that satisfies the standoff requirement. The world coordinate system is shown, where z=0 on the reference table of inspection. As an initial assumption, we choose a tilt angle on the digitizer of 45 degrees with respect to the X-Y plane to eliminate, as much as possible, angle of reflection limitations. This angle allows us to maximize the capture of both side walls and floors in one view. Depending on the choice of scanner areas, full or half, the digitizer height hs is calculated to obtain maximum resolution using the angle B, such that,

$$B = \min(\theta max, \phi max), \qquad (17)$$

$$hs = l + 2o\ /\tan B\ , \qquad (18)$$

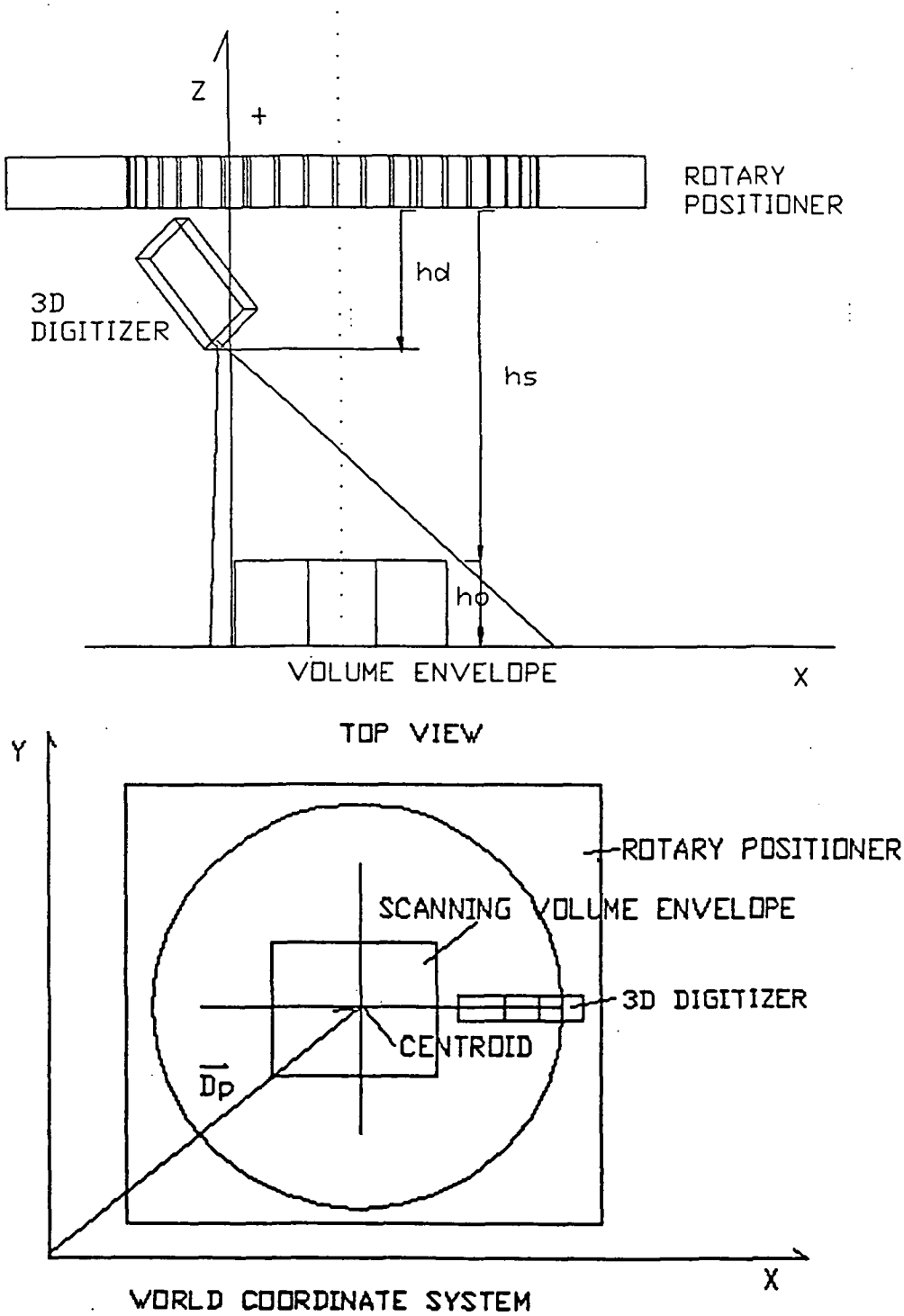

Figure 3.5. 1-Axis Positioner Geometry

as shown in Figure 3.6, and o is the scan overlap. If $\sqrt{2}$.hs is greater than the digitizer standoff, then we set hs equal to the digitizer maximum standoff and solve for 1, which is the length of the digitizing square volume, setting a limit to the field of view. Using half scanning increases the resolution of the measurement. Having obtained the scanner height, we obtain the rotary table position vector R, centered at the centroid at a height (hs + hd + ho) above the X-Y plane.

$$\vec{R}= 1/2\ \vec{i} + 1/2\ \vec{j} +(ho+hs+hd)\ \vec{k}. \qquad (19)$$

We can then calculate d, the distance the center of the digitizer is away from the center (the center of the detector lens, see Figure 2.2). This gives rise to the digitizer translation position referenced to the rotary table coordinates,

$$\vec{Dp}=d\vec{i}=o\vec{j}=Hd\vec{k}\ . \qquad (20)$$

Depending whether concave or convex objects are measured, and if a half or a full scan is desired, the distance d is calculated according to having the 45 degree center scan line at different points on the volume field of view as shown in Figure 3.6. Care has to be taken that ho< Zrange for the digitizer. Having calculated the construction geometry, we can input these parameters into the mechanics of integrating the views so that all points are compatible regardless off the digitizer position.

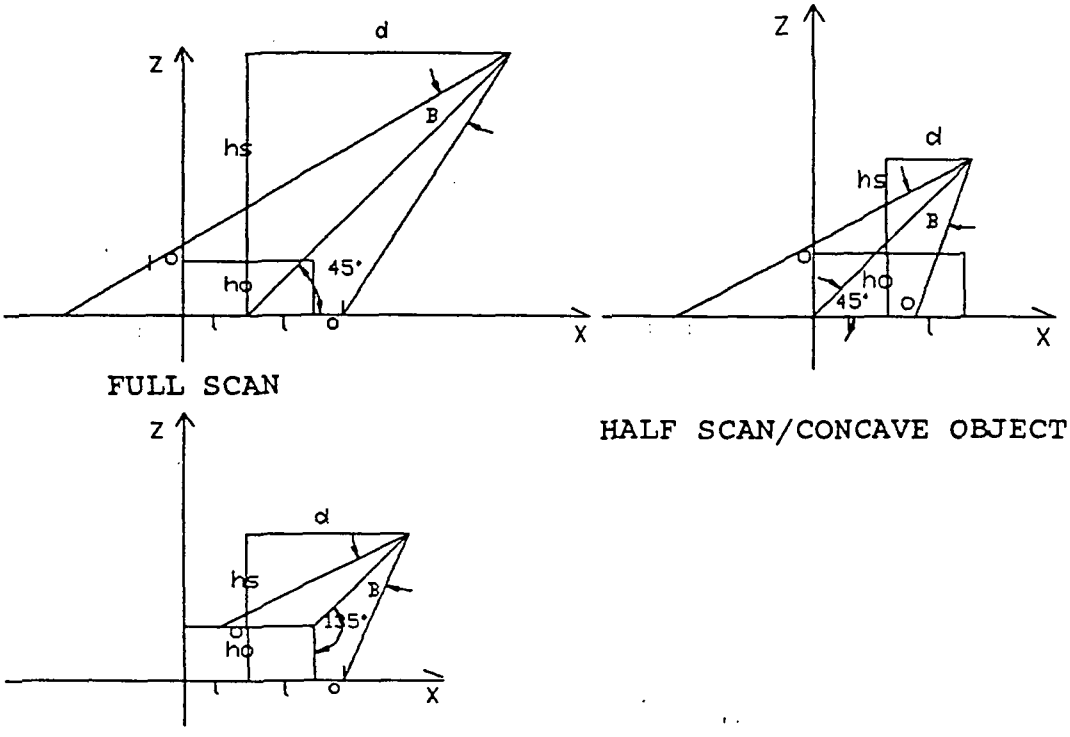

Figure 3.6. Possible Scanning Area Choices.

Integration Mechanics

Once the parameters for the construction of the positioner are calculated, the integration geometry is derived for the set-up. We use the 3-D coordinate translation and rotation transformations that are used for robotic end effector tracking. We derive the rotation and translation matrix of the rotary table with respect to the center of the world coordinate system as,

$$\begin{vmatrix} \cos B & -\sin B & 0 & 1/2 \\ \sin B & \cos B & 0 & 1/2 \\ 0 & 0 & 1 & ho+hs+hd \\ 0 & 0 & 0 & 1 \end{vmatrix} \qquad (21)$$

The angle of the rotary table displacement, B, can be received electronically from the motorized positioning system. The digitizer position with respect to the rotary table, and its respective transformation, is given as,

$$\begin{vmatrix} -0.707 & 0 & -0.707 & d \\ 0 & 1 & 0 & 0 \\ -0.707 & 0 & -0.707 & -hd \\ 0 & 0 & 0 & 1 \end{vmatrix} . \qquad (22)$$

There is a translation of Dp from the center of the rotary table, and a rotation about the Y-axis of 135 degrees. Therefore, to obtain a world coordinate representation of a digitized view, we multiply the digitized point vector (i subscript) by the compound transformation of all the translations and rotations that the digitizer is subject to

from the world coordinate system, and obtain points that can be integrated with other views (w subscript). For this geometry, the compound transformation is calculated to be,

$$CT = \begin{vmatrix} -.707\cos B & .707\sin B & .707 & .707(ho+hs+hd-1/2)+d \\ \sin B & \cos B & 0 & 1/2 \\ -.707\cos B & .707\sin B & -.707 & -.707(ho+hs+hd+1/2)-hd \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

and,

$$\begin{vmatrix} xw \\ yw \\ zw \\ 1 \end{vmatrix} = |CT| \cdot \begin{vmatrix} xi \\ yi \\ zi \\ 1 \end{vmatrix} \qquad (23)$$
$$(24)$$

Point elimination or averaging algorithms can be used to control the point density and/or to average errors in digitization. This section presents a positioning geometry that is simple, cost effective, and may have a wide range of uses. The mechanics of the view integration for this application are arrived at, and should serve as a guide for deriving other geometries.

CHAPTER 4

COMMERCIALLY AVAILABLE EQUIPMENT

The theoretical approaches presented in Chapter 2 have been published as technical papers within the last five years. This may indicate that the systems available commercially are very new and their implementation in industry has not reached its full potential yet. Three-dimensional digitizers are bound to improve as refinements come about through experience and implementations. The performance specifications of the state of the art 3-D digitizing systems are presented. A vendor survey form was sent out to companies that offer 3-D digitizers. To evaluate these systems, a criteria identification section explains the performance issues for this technology. A comparison of the systems is given showing the strengths and weaknesses of certain systems. A comparison between the Moire profilometry and the laser triangulation systems is presented.

Evaluation Criteria

The main objective for 3-D digitizers is to achieve accurate X-Y-Z coordinate measurements for a large measurement range. Additionally, this measurement should be done as quickly and automatically as possible since a high point

density measurement is needed to describe a 3-D object (another basic requirement for 3-D digitizers). The output data obtained from the digitizer should also be the data requested in the proper format. These performance requirements, as well as other factors determined by each application, such as robustness, system cost, and ease of use, are taken into consideration when evaluating non-contact measurement systems. Following is an explanation of the evaluation criteria.

Accuracy

Although generally orders of magnitude less accurate than traditional contact measurement devices, electro-optic digitizers offer measurement accuracies sufficient for many industrial applications. The sources for inaccuracies, generated by most of the system components, are described as follows.

Light Source Inaccuracy. The light source directly affects the system accuracy because parameters relating to the location and pattern of the projected light on the object are used for determining the X-Y-Z measured coordinates. In laser based systems, the scanner angles of deflection (θ,ϕ), which are inherent to error, enter into the coordinate equations (3),(4),(5),(6). Also, the diameter of the light spot minimizes the position resolution inducing error. In Moire profilometry systems, the projected grating may not be normal

to the X-Z plane which creates errors for all measured points, and the optics may distort the pattern inducing phase shifts not taken into account when modeling the system. The grating may not be perfect, and blurring can create errors.

Light Detector Inaccuracy. Sensor resolution mostly determines system measurement accuracy. Discrete photodetector arrays, as well as ccd's, offer resolution to 1 part in the number of discrete cells, although sub-pixel resolution can be achieved by computing the centroid of the light spot, which betters the resolution by a factor of two. Lateral effect photodiodes offer increased resolution (1 part per million), but their accuracy is determined by the signal to noise ratio of the detector and the electronics that convert the signal into digital form. The resolution can be calculated for linear detectors by the expression,

$$res = l/SN \qquad (25)$$

where l is the detector length, and SN is the signal to noise ratio. Analog position detectors are also subject to more ambient light noise than discrete structures. All other optical components such as focusing lenses and mirrors also induce errors due to their physical imperfections.

It is important to note for some geometries in laser based systems, some of the detector resolution is not fully used for height measurement, but is lost due to geometrical considerations. Namely, the detector picks up x- and y-position information which is redundant, since the scanner

deflection provides this information. The synchronized approach, as well as other techniques using telecentric scanning, attempts to maximize the resolution usage. Also, the detector position range has to be matched according to the range of the measured coordinates.

Range and Standoff

Many attempts have been made to extend the usage of this technology for long range applications such as robotic guidance and vehicle navigation systems. Since the accuracy is determined by the detector resolution, extended ranges mean losses in accuracy. Three-dimensional digitizers are limited in range also because of optical non-linearities, focus, and magnification considerations imposed by extended ranges. Focusing is the main problem, since the light source cannot project with accuracy the desired pattern of light. The detected spot will be blurred and thus position resolution will decrease. Many attempts have been used to solve this problem such as tilting the detector to achieve a non-blurred image. Lens corrections are constantly being redesigned to eliminate this problem. Additionally, optical power and increased ambient light noise concerns reduce the detector resolution which reduces the system accuracy and speed. Increasing the source power and using light filtering techniques can partially resolve these problems. Since 3-D digitizers can be tuned to certain ranges, the ease of

conversion is a desirable factor to have, unless the system is used over a constant range.

Shadowing and Reflectivity

As we attempt to measure surfaces close to normal to the line of projection (large slope in z-), inaccuracies are induced, since the projected light covers a much larger area (see figure 4.1). The area of the light spot tends to infinity as the surface becomes parallel to the line of sight; therefore the detector makes an incorrect measurement. For this reason, digitizers must be placed at different locations for accurate capture, making sure that the slope in z- does not exceed a certain angle. In Moire profilometry systems, the z-slope is limited by the projector and detector geometry by the expression

$$\partial |h(x,y)/x|_{max} < lo/3d \quad . \qquad (26)$$

Increasing the value of the right-hand expression will lead to decreased resolution. A high z-slope also gives rise to image overlap and unmeasurable surfaces as shown in Figure 4.1. Due to the uncertainty of the reflective qualities of the object, uneven reflectance affects the quantity of the detected light which can add errors in the calculation of the coordinates. For example, if the surface is very polished, there may not be enough randomly scattered light for collection by the detector lens.

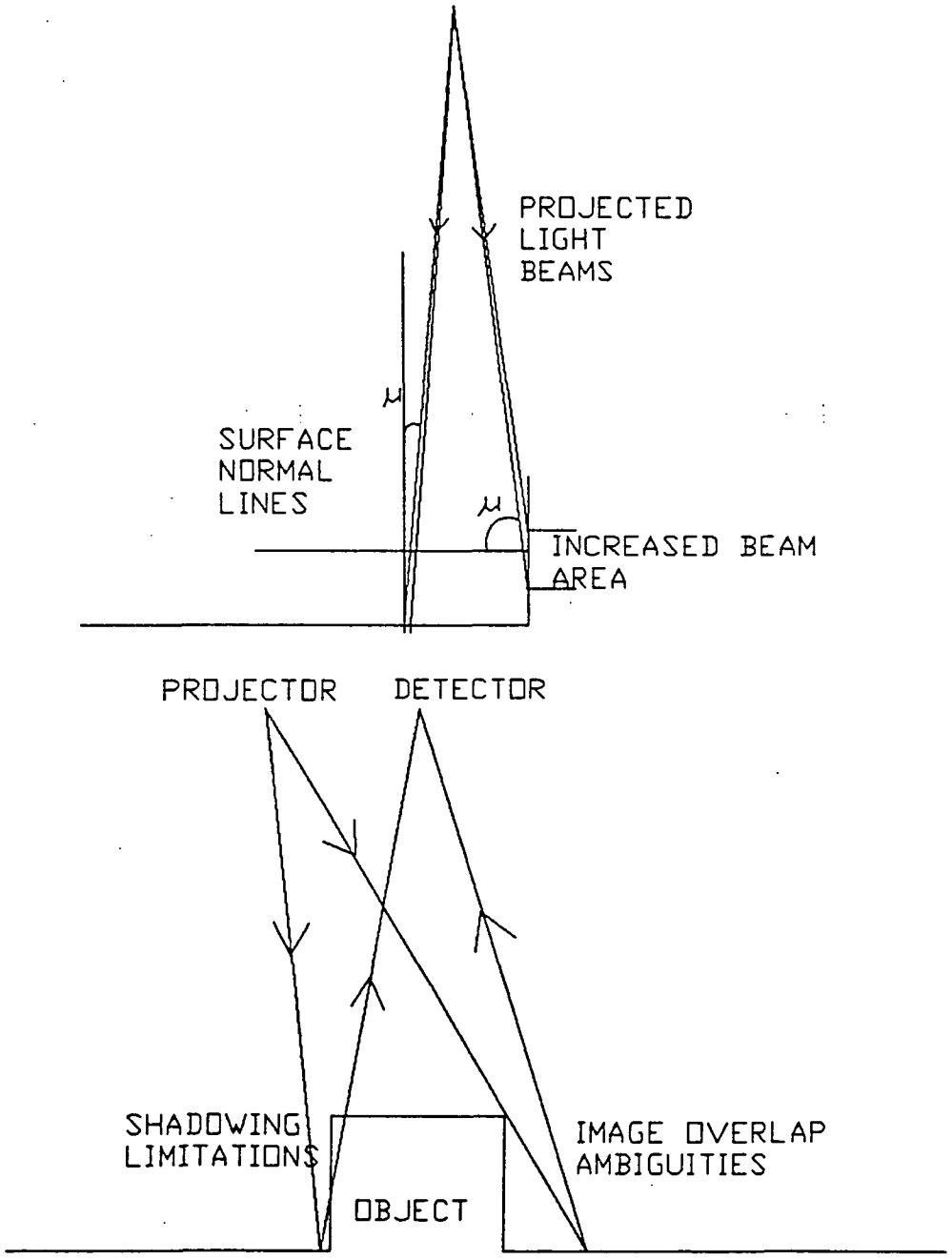

Figure 4.1. High Slope Shadowing Effects.

Digitizing Density and Speed

One of the best features of 3-D digitizers is that they can measure a vast number of points in a small area. For intricate objects, accurate measurement specifies a high measured point density. This density needs to be modifiable since there are circumstances when excessive data is a problem, and conversely not enough points may not give the resolution desired. A good 3-D digitizer should be capable of changing the point density automatically. Also, digitizing speed is an important requirement for inline applications, such as in an automated quality inspection system. For moving parts, sometimes the scanning speed may be too slow. Here, Moire based systems offer a clear advantage, since all the data capture is done in the frame time for a ccd element which can be in the order of 20 ms. Nevertheless, the X-Y-Z representation needs to be obtained and may take longer to generate than in a triangulation based system.

Software Capabilities

Once the data for a view is obtained, it may need to be processed so that useful information is obtained. View integration is a necessary feature when more than one view is needed to digitize the object. Data reduction, compression and conversion programs are needed for the effective input of the data into a CAD program. This process can be very time consuming, and render the process inefficient. The 3-D

digitizer system should contain the right software to maximize the efficiency for a given application.

Other Considerations

Physical considerations such as dimensions and weight may be an important factor if the digitizer is mounted on a positioning system, or needs to measure in difficult to access areas. The system needs to be protected from the hazards of an industrial environment. The robustness of the digitizer should be considered so that the delicate optics are not mistreated during use.

Equipment Specifications

Most vendors that offer 3-D digitizing systems were found through industry directories and trade publications. The digitizers had to conform to the requirements mentioned in Chapter 1. Table 4.1 shows the tabulated results obtained through interaction with several companies that have made implementations of their systems in an industrial environment. Many vendors offer consulting and customization work for integrating this technology in a particular application. This information does not represent the totality of the systems available commercially.

Comparison of Systems and Approaches

There are many factors to be taken into consideration when selecting a system. Economic considerations, as well as

TABLE 4.1

3D LASER DIGITIZING SYSTEMS.
TECHNICAL SPECIFICATIONS.

	VENDOR NAME	MODEL #	METHOD	ACCURACY X	Y	Z	SCANNING DENSITY X	Y
1)	HYMARC	HYSCAN	LT 2D	0.002" a	0.0005"	.001*Zmax	4096	10K
2)	EOIS	MK VII	MP 3D	0.0005"	0.0005"	.0025*l	4096	4096
3)	LASER DESIGN	3D LASER DIGITIZER	LT 2D	0.002"	0.001"	0.002"	4096	10K
4)	WYKO	MAX	LMP 3D	0.001"	0.001"	.001*Zmax	510	492
5)	CHESAPEAKE LASER SYSTEMS	TDP 1000	LT 2D	0.0005"a	0.001"	.001*Zmax	10K	10K

	Z- RANGE MAX	STANDOFF MIN	RANGE MAX	MAX. Z SLOPE	SCANNING SPEED	DIGITIZ. SPEED b.	VIEW INTEGRAT.	SYSTEM COST
1)	4"	1"	6"	1.7	10 KHz	10 KHz	AUTO	100K
2)	12"	4"	40"	1.0	7.7 MHz	51.2 KHz	AUTO	50K
3)	8"	1"	10"	19.1	10 KHz	10 KHz	AUTO	75K
4)	6"	10"	20"	1.0	1.84 MHz	5.6 Hz	N/A	N/A
5)	3"	1"	25"	1.7	5 KHz	5 KHz	AUTO	N/A

a Accuracy dependent on mechanical stage.
b Scanned or measured points per second.
c l = scan length.
d L=Laser; T=Triangulation; MP=Moire projection;
e Z Slope = max(dZ/dX,dZ/dy)

vendor support, are key items that have not been discussed. Technically, the application will dictate the key characteristics needed for the successful implementation of a 3-D digitizing system. The availability of a turnkey system including interfacing with a CAD system may be an important consideration. Positioning systems are also a major consideration and have to be carefully designed to maintain accuracy and flexibility of measurement ranges. The evaluation of the software must be meticulous since the productivity of the digitizing system is directly dependent on the ease of use made possible by the software. The equipment specifications should be a guide for the evaluation and selection of a 3-D digitizing system. Rather than evaluate each system independently, we will compare Moire profilometry systems versus laser based triangulation systems.

Profilometry vs. Triangulation

It is interesting to note that both systems offer accuracies that are very much in the same range. Also, many vendors offer a tuned set-up that matches the requirements of a particular application and can be attained by using both methods. Nevertheless, profilometry systems offer some advantages over triangulation systems. First, there are no moving parts in profilometry systems. The geometry for triangulation systems is far more complex, and is more subsceptible to environment distress because of the delicate

nature of the scanners and other optical components. Second, profilometry systems are very flexible in terms of changing ranges and sensitivity. The sensitivity can be increased simply by changing the grating in the Moire projector. The standoff and the field of view can be extended simply by changing lenses on the ccd camera and the Moire projector. Many of the components used in profilometry systems can be purchased off the shelf, such as ccd cameras, frame digitizing boards, lenses, etc. These are factors that may reduce the cost of the system as well. Additionally, the use of lasers may be hazardous for eye contact in some applications, especially when the standoffs are high, and thus the power as well. Nevertheless, there are factors that make laser based systems a better alternative for some applications.

The laser digitizer probes are very compact units that can fit in many areas that a profilometry set-up cannot. They are comprised of one unit for the projector and detector instead of two. This reduces significantly the geometry set-up, since in profilometry, all parameters such as, lo,d,O have to be measured. Additionally, some triangulation systems can measure accurately z-slopes that exceed 80 degrees, whereas the practical limit for profilometry is approximately 45 degrees.

The above results show a partial list of available 3-D digitizing systems and their capabilities and limitations. Three-dimensional digitizing systems can support a wide range

of functions within CIM that will improve productivity and quality.

CHAPTER 5

CONCLUSIONS/POINTS OF RESEARCH

The theories of operation of many of today's commercially available equipment have been discussed. A breakdown of 3-D digitizing systems into components has been done, including an application example of a low cost positioning system. The specifications of available equipment are presented, as well as a discussion of the capabilities and limitations of this new technology. Three-dimensional digitizers should continue to improve, and their use should become more widespread in a number of areas due to the performance characteristics described in this paper.

Research aimed at increasing the performance of these devices will enable a wider range of uses for this technology. Work is currently underway to eliminate the need for precise positioning by including a reference object in the field of view to give information on digitizer coordinates, so that view integration can be achieved. This will lead to the feasibility of a hand-held compact digitizing unit.

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Announcing the
Final Examination
Mr. Daniel K. Nasser
for the
Degree of Master of Science
November 22, 1989
2:00 p.m.
CEBA 381

Research report title: Non-Contact, Three Dimensional Object Digitizing Systems.

The new field of non-contact 3D object digitization has many applications in industry. The state of the art in technology uses electro-optic measurement techniques such as laser based triangulation and phase measurement projection Moire profilometry, for obtaining a non-contact, X-Y-Z coordinate representation of an object. This paper presents an overview of the theories of operation, as well as an analysis of a basic system. In a separate component, the performance issues, as well as potential applications within computer integrated manufacturing (CIM), are discussed. A market study for commercially available systems shows the technical specifications and capabilities, of the state-of-the-art in 3D object coordinate digitizing technology. A comparison of the different systems and approaches is presented as well.

Outline of Studies
Major: Industrial Engineering

Committee in Charge	Educational Career
Dr. Yasser A. Hosni, Chair	B.S., 1986
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Dr. J. E. Biegel	

Approved: Yasser Hosni 11/17/89
Committee Chair Date

Any member of the faculty is welcome to attend.

Workstand Design

Interim Report

UCF / KSC COOPERATIVE AGREEMENT

Industrial Engineering Project

Project 6:

PRODUCTIVITY IMPROVEMENT TECHNIQUES

Workstand Component

Interim Report

by

John Creech
Yasser Hosni

January 1990

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VII. Evaluation of New Designs

WORKSTAND COMPONENT

I. STATEMENT OF PROBLEM

The NASA/UCF Research Team is presently investigating improvements in the design of workstands used in the Orbiter Processing Facility in performing tasks related to the repair and maintenance of the Thermal Protection System on the Space Shuttle Orbiter vehicles. The overall objective of the study is to expedite repairs and to improve the accuracy with which these repairs are accomplished.

TPS maintenance is performed after each flight on all external surfaces of each of the orbiters, as well as in the payload bays. However, since most damage to the TPS is sustained on the lower and flight control surfaces, particularly in the aft section, the team is restricting its study to maintenance tasks performed from stands positioned on the OPF floor.

Improvements in these procedures is critical to shortening the orbiter process flow since maintenance of the TPS system is often technically restricted to being performed after modifications and/or maintenance to the vehicle itself.

II. GENERAL REQUIREMENTS

Processing of the TPS of the orbiters is unique in the aerospace industry due to several conditions existing in the OPF environment, the design of the orbiters themselves, and the nature of the tasks accomplished:

1. The thermal tile are easily damaged by contact with equipment, tooling, workstands, or the skin of the technicians.

2. Many maintenance activities, both on the vehicle and the tile, are performed simultaneously; hence, the work area is typically crowded by personnel, equipment, and workstands of various designs. All of these obstacles must be "worked around".

3. The environment is restrictive in the materials and designs that can be used in the construction of the workstands. Primary restrictions concern the flame spread rate and out-gasing under fire conditions of the materials used in construction, as well as the mobility of the stands and the level of cleanliness that must be maintained.

4. Repair or replacement of TPS components requires extreme precision in most cases, dictating that the stands be rigid and stable.

5. Most tasks are presently performed in out-of-position postures, that is, overhead. New stand designs should minimize visibility, vision, and fatigue complications in these postures.

6. The maintenance processes vary significantly in the surface area that is covered in accomplishing them. Repair of individual tile and removal and/or bonding of new tile is typically restricted to an area of one square foot. Measuring of the step and gap between several tile may typically have the technician traversing areas of several feet.

7. Most of the 128 processes accomplished in TPS maintenance require the labor of only one person. However, all processes are inspected and approved by quality control and engineering personnel at numerous stages. Hence, ingress and egress from the working/inspection position must be accomplished easily and quickly.

8. Task accomplishment is heavily dominated by documentation and referral to written procedures - there must be immediate and easy access to paperwork and manuals.

III. SPECIFIC REQUIREMENTS

1. The workstands must provide easy access to the lower surfaces of the orbiters which range from 8 to 12 feet from the shop floor in the OPF. Male and female technicians of normal height ranges use the stands.

2. The workstands should have infinite height adjustment to accommodate the range of height of the work areas, as well as the range of height and reach of the technicians. The stands' height should be easily adjustable by one person, and preferably would be adjustable from the technician's working position.

3. The design should provide postural support for the technicians in accomplishing overhead processes thereby minimizing the effects of fatigue and visibility of the work area.

4. Handrails should be removable to permit ease of

movement about the shop floor without the possibility of damage to tile when moving from a high work area to a low work area.

5. Wheels used on the workstands should be of large enough diameter to allow easy passage over floor gratings used to cover equipment chases and drainage channels. Floor grating is a rectangular grid, 4.25" X 2.5", with openings of 3.25" X 2.0".

6. Proof testing - stands should be able to withstand static loadings of 375 lbs. for each person that they will accommodate without failure or significant deformation.

   Handrails should be able to withstand loadings of 275 lbs. applied downward at a 45 degree angle from vertical.

   Steps and/or ladder rungs should be able to withstand static loading of 375 lbs.

7. The design of the workstand must conform to NASA document SW-E-0002, Revision C, May 11, 1987, Space Shuttle Ground Support Equipment General Design Requirements.

8. Materials used in construction must conform to NASA document NSTS 08242, which specifies materials permissible for use in the OPF.

9. Human engineering criteria should conform to military standard MIL-STD-1427C, May 2, 1981, Human Engineering Design Criteria for Military Systems, Equipment and Facilities.

IV. CURRENT STAND DESIGNS

Stands currently in use are generally of two designs described below, although some tasks are accomplished from stands used for vehicle maintenance such as the rectangular stands around the nose and main landing gear, and the large circular stands that are semi-permanently erected around the supporting jack stands in the area of the external tank attachment points. It should be noted that these latter stands can only be used when TPS processes do not directly conflict with vehicle maintenance being performed from these stands.

One-to-four Person Stands:

Platform area = 48" X 72"
Floor space occupied = 73" X 49"
Minimum platform height (from floor) = 48"
Maximum platform height (from floor) = 72"
Height adjustable in four (4) 6" increments by Pip pin removal and reinstallation
Access/egress by vertical ladder, 4 rungs at 14" spacing
Handrails - adjustable height - 30", 36", 42" - Pip pins
Four castered wheels, 4" diameter

Advantages:

- Allows access to large work areas
- Allows performance of tasks requiring more than one technician
- Height adjustable
- Rigid and relatively safe

Disadvantages:

- Lack of infinite height adjustment
- Difficulty in movement - heavy, and wheels too small to pass easily over floor gratings
- Requires several people to adjust height manually
- Requires standing or sitting position to perform tasks overhead
- Occupies large floor space restricting performance of other TPS and vehicle processes
- No provision for tooling or equipment stowage or attachment other than on working platform
- No provision for immediate access to paperwork and manuals required for task accomplishment -these items are typically placed on the work platform or on the shop floor.

<u>One-person Stands (non-adjustable height)</u>:

Platform area = 24" X 24"
Floor space occupied = 73" X 30"
Platform height (from floor) = 69"
Access/egress by inclined stairs, 6 steps, 30 degrees from vertical
Handrails - 3 sides of platform, both sides of stairs at height of 32"
Two rigid wheels, one or two castered wheels, 4" diameter

Advantages:

- Lighter weight - more portable
- Occupies smaller floor space - easier access in tight quarters

Disadvantages:

- Allows only one person on stand at a time
- Lack of any height adjustment - limits usability by cramping technician in low work areas, extending reach in high work areas
- Relatively unstable - light weight and small size for heights reached
- Difficulty in movement - wheels too small to pass easily over floor gratings
- Requires standing or kneeling position to perform tasks overhead
- No provision for tooling or equipment stowage or attachment, other than on working platform of restricted size
- No provision for immediate access to paperwork and manuals required for task accomplishment -these items are typically placed on the work platform or on the shop floor.

VI. ERGONOMIC/ENGINEERING ANALYSIS OF CURRENT DESIGN STANDS

This section examines the design and use of the current stands from several perspectives: safety, accepted industry standards for workplace design and working positions, anthropometric dimensions of humans, and task performance.

Reference is made to diagrams and information extracted from Humanscale (TM), a human engineering design aid published by the MIT press; the Handbook of Industrial Engineering; and MIL-STD-1472C, Human Engineering Design Criteria for Military Systems, Equipment, and Facilities.

Comments on task performance and methods used by TPS technicians is based on approximately 15 hours of task observation and numerous informal interviews with TPS technicians, supervisors, training staff, and Lockheed and NASA engineers.

Observation of Work Positions Assumed

The configuration of the orbiter and the tasks performed on it (study limited to lower and flight control surfaces) require that virtually all processes be performed in non-standard work positions, that is, overhead.

The literature searched indicates that there is little data available on task performance in these postures. In fact, the postures and positions assumed are not recognized as anthropometrically acceptable for precision work when considering the limits of human reach and vision. It is

evident that technician performance may be degraded by problems associated with visibility of the work area and fatigue brought on both by working in less than optimal postures, and in elevating the eyes and rotating the neck backward to view the work area. Further, the work positions assumed by technicians, and the mobility/adjustability of the stands, have significant safety implications.

The following sections discuss each of these topics in more detail.

Typically, though all tasks require work on a surface that is overhead, the technicians are not continuously involved in reaching or viewing the surface. Across all of the 128 processes that are performed in tile maintenance, work on the overhead areas is actually performed about 30% of the time. Since all processes are paperwork and inspection intensive, the technicians often turn away from the work area to record data, steps accomplished, and/or to check procedure manuals. Further, they often exit the working position to permit QC personnel access for inspection of work accomplished.

Some procedures, particularly Process 301, tile bonding, and all of the 200-series processes that 301 requires for cavity preparation, restrict the technician to a small work area, and require unusual postures for extended periods of time. Other processes such as 310, step and gap measurements, may require that the technician traverse large areas and do not require extended periods of overhead work.

Typically, in performing maintenance from the small work stands, the technician places his tools, equipment, and paperwork on the platform of the stand and works either from the standing or kneeling position from a step or the platform itself, whichever allows easiest access to the work area. The stands are often "jerry-rigged" with foam padding to ease kneeling or bending over the handrails. Special tooling and meters are often taped to the stands in the best position attainable. It is not uncommon, due to the limited space on these stands for the technician to leave the paperwork and manuals on the floor and to repeatedly climb and descend the stairs during the performance of a process.

On the large workstands, which permit covering larger work areas, the technician has more area to place equipment/paperwork, and is not as likely to get on and off of the stand as often. An office chair is usually placed on the workstand where the technician sits to accomplish paperwork. It is not usual for technicians to work sitting on, or leaning backwards over the handrails, sometimes with their legs wrapped around the center horizontal rail or corner vertical rails for stability. On several occasions, technicians have been observed sitting on the top rail with feet simply rested on the middle rail, while working overhead

reaching at eye level and 20" in front of the spinal vertical, while holding no weight (or exerting no pressure), is only 5 minutes. When holding a weight of 2.5 pounds (the laser step-and-gap tool weighs 2.4 pounds), this time is reduced to approximately one minute.

Greenberg and Chaffin report that if an object of the given weight is to be held repeatedly, it should be held for less than 10% of the "time to reach significant fatigue" on each occasion. Intervals between each event should be at least six times the holding time.

From this diagram, it can be expected that TPS technicians reach significant muscle fatigue levels, especially when using heavier tooling such as the IML Comparator, and often in other process accomplishment.

The level of fatigue reached has serious implications for the precision of the tasks performed. As E. Corlett reports in the Industrial Engineering Handbook, "on ceasing strong muscular activity, a worker will experience a tremor induced by way of the muscles which will prevent finely controlled movements from being accomplished successfully. Similarly, the ability to recognize variations in smooth movements - for instance, by workers sanding furniture or testing the sliding fit of drawers - will be reduced in sensitivity after the performance of heavy work."

Corlett's research translates directly to TPS processing. It is not uncommon for technicians to heavily exert themselves in moving or adjusting a workstand, and return immediately to very precise work such as cavity preparation (sanding) or checking tile or gap filler clearances with feeler gauges (sliding fit). It is also likely that leg, back, and arm muscle tremor is induced by holding uncomfortable postures for extended periods, or by reaching overhead for several minutes.

Access to Equipment and Paperwork

With one exception, no provision is made on the current workstands for convenient storage of, or immediate access to equipment, materials, or paperwork.

As noted previously, when using the small stands, technicians typically place their working materials on the platform of the stand or on the floor. If the materials are placed on the platform, their working positions thereon are restricted or they must work from the steps. If the materials are placed on the floor, they must repeatedly climb up and down the steps. Some of the small stands have a tray under the platform but access to it is only possible from the floor.

When using the large stands, materials are usually placed on

and leaning slightly backward. It is reported that on other occasions, technicians have tied office chairs or laboratory stools to the handrails to achieve a more comfortable working position.

Safety - Slips or Falls

Historical data relating to injuries or falls from workstands has not been investigated, but there is significant potential for injuries under the existing working conditions.

Due to the adjustability and mobility problems addressed below, technicians are likely to create unsafe conditions in order to expedite process flow.

The most likely scenario for an accident would involve a fall from a position sitting on or leaning backward over the handrails of any of the workstands. An individual's sense of balance is significantly reduced when their line of sight is rotated from horizontal toward vertical, particularly when visual references are limited, as is the case when performing tasks overhead on the orbiter.

The second most likely type of accident would result from toppling the smaller stands, particularly the three wheeled type. These stands are not particularly rigid or heavy, and have a base width only six inches wider than the work platform. A rapid shift of the technician's weight from one side to the other, or a position assumed that is well over the 32" high handrail could topple the stand. The situation could be complicated by the attachment of tooling bars with significant weight applied outside the rail, by the weight of more than one technician leaning over the rail, by a rapid shift in position by the technician, or by a large technician applying vertical pressure to a work surface outside the rail of the stand.

A third type of mishap could occur as a result of a fall from the vertical ladder of the large stands. Vertical ladders are not desirable for platform access, and the spacing of the rungs on the large stands exceeds the maximum recommended for the U.S. worker population (14" vs 12").

Other safety concerns are addressed in sections following, and relate to: 1) possible back strain resulting from moving or adjusting the stands; and 2) fatigue resulting from prolonged exposure to unusual postures and viewing angles. The fatigue problems could easily contribute to the likelihood of a fall.

Safety - Height Adjustability

Two factors, the height adjustability and the mobility of the stands (following section), contribute to the assumption of

uncomfortable and/or unsafe work postures by the technicians.

When the work area is low, the lack of any adjustability of the small stands requires the technician to stoop on the platform or to work from the steps, either standing or kneeling. His stability is reduced as a result of the small area for foot movement when standing on a single, or two steps, and slips or falls are more likely.

Reaching high areas from the small, non-adjustable stands is difficult and can easily exceed the work envelope for the shorter technician population. This also may cause the technician to extend himself over the handrail or to sit on it.

Stooping on any of the platforms severely complicates the technicians ability to reach overhead work areas or to comfortably rotate the head and eyes to view the work. See Diagram 1, and the section on Vision/Visibility of Work Area for criteria relating to head and eye rotation and field of view.

The adjustment of the height of the large workstands cannot be accomplished by less than four persons. The platform of these stands is adjusted by removing and replacing Pip pins located at the four corner supports and normally requires four persons to both lift the weight of the platform and remove/replace the pins. Such an adjustment requires that the technician obtain the help of at least three other persons and interrupts these other persons' performance of their respective tasks. Consequently, it is more likely that a technician, particularly under time pressure, will not adjust the stand to attain as comfortable a position as possible, and will instead resort to other measures to continue work (stooping, reaching, sitting or even standing on handrails, etc.).

Even when four persons adjust the large stands there is significant weight to be lifted or lowered while simultaneously attempting to remove or replace the pins. The potential for back injury is high, particularly as the technicians attempt to hold the weight of the platform and bend over to replace the pins. This potential for lifting injuries is significantly increased if fewer than four technicians attempt to adjust the stand.

Safety - Mobility

Problems with the mobility of the stands detracts from work performance when considering set-up time, but also has safety implications.

The most significant problem is in moving the stands over the

floor grates and/or cables or hoses on the OPF floor. All stands have wheels of 4" diameter and are easily hung up in the grating. The stands can usually be passed over the gratings by crossing them diagonally, but the castered wheels (one or two on small stands, all wheels on large stands) have a tendency to rotate and hang themselves in the grate causing an abrupt stop. The 4" diameter wheels used on all of the stands will drop .875" to 1.0" into the grid of the gratings used in the OPF (3.25" X 2").

Once the wheels are hung up, it is difficult to move the stands and often takes the effort of more than one technician. Aside from consuming the productive working time of one or more technicians, considerable lifting and pushing force is required to free a stand from the grating. Lifting injuries could result, particularly among the smaller female technician population.

Some difficulty is experienced when passing over cabling or hoses laid out on the OPF floor, particularly when moving the larger stands. Again, depending on the size of the obstacles that must be passed over, considerable lifting and pushing force may have to be exerted, especially when moving the larger stands to a work area. This sometimes requires the effort of more than one technician, and the effort required can exceed safe lifting limits.

A further consideration relating to the small diameter of the wheels is the possibility of damage to cables or hoses that are traversed.

Vision/Visibility of Work Area

Since the technicians are working on overhead surfaces, their "strategy" appears to be to position themselves with their heads as close as possible to the orbiter in an attempt to place the work area in their most comfortable field of view, i.e., avoiding, as much as possible, upward eye rotation and backward neck rotation. Even so, the precision required in the tasks accomplished dictates that the technician establish a direct sight line to the work area. As pointed out below, even with the head close to the orbiter surface, seeing the work area can be difficult.

Diagram 1 illustrates the normal sight lines in standing and sitting positions, and the limits of easy and maximum eye and head movements possible to view and work on overhead surfaces with a vertical posture. It is important to note several points from this diagram that relate to processing of the orbiters:

1. Directly viewing any overhead surface, especially close to the head and within the reaching range, requires a considerable rotation of the head and/or

eyes.

2. One or the other of the rotations (eyes or head) must exceed the "easy" range to achieve a sight line over 30 degrees above the horizontal.

2. To achieve a sight line of over 60 degrees above the horizontal, both the head and eyes must be rotated beyond the "easy" range.

3. To achieve a sight line directly overhead (90 degrees), the eyes must be rotated to their maximum, and the head within one degree of its maximum range.

Ergonomics research indicates that rotations of the head or eyes beyond the easy range are fatiguing. It can also be expected that visual acuity and balance is reduced in these head and eye positions, and can induce errors in task performance.

As pointed out earlier, stooping on the workstands complicates the problems of visual acuity and fatigue by rotating the spine forward and requiring further upward rotations of the head and eyes.

The technician can accomplish part of the upward looking rotations by leaning backward, but this posture is extremely fatiguing and can cause back strain or injury, particularly if he is supporting any weight (tools, materials, parts), or is exerting any pressure on the working surface. If the technician leans over the handrails, there is an increased possibility of a slip or fall.

Muscle Fatigue

On the lower surfaces of the orbiter, all tasks involve work that requires reaching above shoulder level while holding tools or equipment, or while exerting pressure on the work area. As reported earlier, overhead reaching and viewing occupies only about 30% of actual task accomplishment time, but even this proportion can be significantly fatiguing, even if no weight is supported, and certainly if heavy tools or materials are lifted above shoulder level.

Diagram 2 illustrates the "Holding Time to Unacceptable Levels of Fatigue", as reported by L. Greenberg and D. B. Chaffin (Workers and Their Tools, Pendell Publishing Company, 1977). The two graphs relate to data collected in the sitting position; it could be expected that standing postures would result in equal or greater fatigue. The values shown are for the male population - for women, no more than two-thirds of the given value should be used.

Note that the time to reach significant muscle fatigue when

the platform of the stand or on chairs placed on the platform. Either alternative restricts working area and requires repeated bending or stooping.

Equipment trays have recently been fabricated that attach to the handrails of the large stands. These trays are not usable on the small stands since they are supported from the middle rail which does not exist on the small stands. The trays are available in limited quantities and range in width from 18 to 48 inches. They can be installed on the inside or outside of the large stand handrails. Most technicians interviewed were unaware of the availability of the trays, and their use has been observed on only one occasion.

Conclusions

In many respects, the currently used workstands are unacceptable for performance of precision tasks on the lower surfaces of the orbiter vehicles.

The safety of workers is compromised by exposure to conditions conducive to falls from heights several feet above the floor, and moving or adjusting the stands may cause muscle or back strain. Further, the working postures assumed by technicians is likely to cause significant levels of fatigue, and possible complications with neck vertebrae and eye muscles.

Processing time is very likely increased by difficulties in moving or adjusting the stands, and by rest breaks, whether planned or not, that must be taken after long exposure to the unusual working postures.

Precision of task performance is also likely reduced by fatigue and reduced visibility of the work surfaces.

It is clearly suspected that optimum technician performance is not being achieved with the use of the current stand designs, and that the complications caused by these designs can be significantly diminished by modification or total redesign of the stands.

VI. NEW WORKSTAND DESIGNS

There are currently three design alternatives being formulated: modification of the current stands, total redesign of the large rectangular stands, and the design of a circular workstand.

The design strategy for the modified or new workstands is directed at increasing technician safety, decreasing the time to perform TPS processing tasks, and increasing the precision

with which these tasks are accomplished.

All current and any added alternatives have, or should have, four elements included in their design:

1. The use of larger and wider wheels - minimum of 8" diameter and 2.5" width, to permit easy rolling over obstacles and zero penetration of the floor gratings.

2. Improvements in the range and ease of height adjustments.

3. Improved access to equipment and paperwork.

4. Features to allow the technician to work in a semi-reclined seating position, or as an alternative, provision for upper body support when standing while leaning backward.

The first three elements are essential. The fourth, reclining the technician, may not prove beneficial for tasks performed that traverse large areas, but should be considered essential for tasks limited to small areas such as repair of one or a few tile, or cavity preparation and/or tile bonding.

Conceptual drawings of the three alternatives currently under study are presented in Diagrams 4,5, and 6. Each includes a device designed to provide a semi-reclined seating position for the technician. The following section details the design parameters for the seating area and is followed by details relating to each of the three alternative workstand designs.

Seat Dimensions

The seat dimensions shown in Diagram 3 are a compromise of several criteria, but generally follow the guidelines for the average adult (lengths, angles) so as to accommodate the range of sizes for the technician population (Humanscale, IE Handbook, MIL-STD-1472). Modifications may be made, but the following criteria should be adhered to:

1. With backrest angles in this range (120 degrees shown), a headrest must be used, and headrest height should not be less than 31".

2. Footrest angles should not allow knee flexion of less than 100 degrees (110-120 optimum).

3. Seat bottom inclination should not be less than 15 degrees (shown) to prevent sliding downward. Angles greater than 15 degrees, if used, will make ingress or egress more difficult.

4. Footrest angle should not be less than 90 degrees (100 degrees shown).

5. Lumbar support should be maintained, via thicker padding or contouring of the backrest.

6. Knee to ankle distance should be adjustable over the range of 15 to 21".

7. Optimum headrest angle for reclined seating positions when viewing objects near the horizontal plane is 10 degrees (shown). However, for this application where the technician is looking overhead, the headrest angle should be adjustable.

8. Seat width should not be less than 19" and hip clearance not less than 22".

9. Work area width should be unobstructed for a width of 40" to allow full arm movement.

Alternative 1 - Modification of Large Stands

The least cost method of achieving the design needs stated above is to modify the large work stands. The small stands cannot be feasibly modified as follows, other than increasing the wheel size, because their railings are of single bar, low-strength contruction.

Diagram 4 illustrates represents an accessory seating fixture that can be easily attached to any of the four side railings of the currently used large stands. It incorporates the seating design described above and in Diagram 3. The fixture should be constructed of the lightest weight materials possible for portability and easy handling, and should use adjustable tracks to make fine adjustments in the seat height. It also includes features to permit adjustment of the tilt angle of the entire seating area.

The rails on the current stands are of sufficient strength to support the weight of this fixture but do have considerable play due to large clearances in the sockets in which the legs of the rails are installed. Clamps similar to those shown in the diagram must be installed at the tops of adjacent (and perpendicular) railings to connect them. These clamps would eliminate the play and add considerably to the bending rigidity of the railing on which the fixture is installed.

Additional modifications to the large stands are highly desirable. First, the wheel size should be increased to the dimensions listed above to aid in mobility. The second

necessary modification would be more complex, that is, improvements in height adjustability.

It would be desirable to provide these stands with infinite increments of height adjustment through the installation of a hydraulic or electromechanical lift device. An alternative design could use a manually operated hydraulic or pneumatic system. Though mechanically feasible, such modification would likely prove to be costly since the stands were not originally designed to incorporate such devices.

It has been reported that stands of similar design, but which incorporate manual height adjustment via turn-screws at the four corners, are in use at other NASA or contractor locations. Design criteria on these stands has not been obtained.

Alternative 2 - New Design of Large Stands

Diagram 5 illustrates a conceptual design for an improved workstand with area large enough for four technicians, or for a single technician to traverse large areas. Its supporting structure, and a removable section in the floor allow it to be placed directly around the large tripods used in tile bonding, to provide close-in, 360 degree access to the bonding area with the tripod in place.

The stand's height is adjustable via hydraulic scissors type mechanisms on each side. The hydraulic system could be manual or motorized, but adjustment should be possible from the work platform.

The handrails are similar to those used on the present large stands to allow attachment of the seating fixture described above and equipment trays designed for the present stands.

Alternative 3 - Circular Stand Design

The third design concept presented is shown in Diagram 6. This design has a circular work platform and handrails and will accommodate the seating fixture and equipment trays. The design allows more flexibility in technician positioning, but is likely to be more expensive to build.

This design can also accommodate the circular seating "bowl" shown to provide continuous seating around the stand in a range of approximately 300 degrees.

Height adjustment is provided by turn-screws in the four vertical legs and again, could be motorized or manual, and should have the ability to be raised/lowered from the work platform.

VII. EVALUATION OF NEW DESIGNS

Prior to finalization of the design of new equipment, there exists a need to conduct experimentation with a prototype seating arrangement. The goal is refinement of seating dimensions and angles for optimum performance with entire range of technician population.

The research team intends to construct a highly adjustable prototype seat and a mock up of the work area to provide overhead surfaces for task experimentation. This testing facility will be located at the University of Central Florida and experimentation will be conducted with a number of student subjects.

Tests will be designed to determine visual acuity and motorskill performance in current technician working positions. Similar experiments will be conducted with the subjects in the semi-reclined position, and results compared with data generated form current working positions.

The experiments will provide a documented evaluation of fatigue levels reached, and performance degradation over time, in both types of positions.

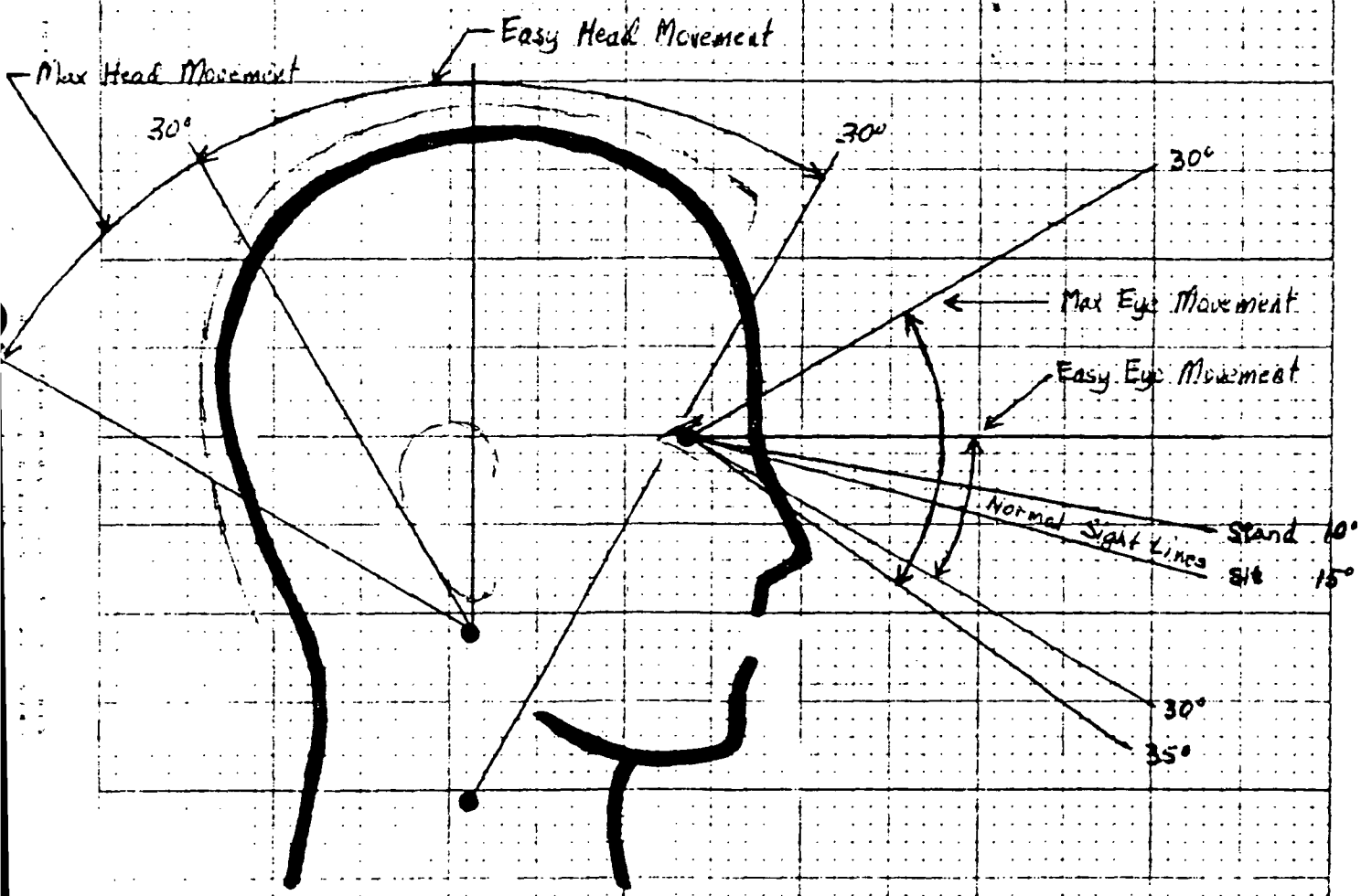
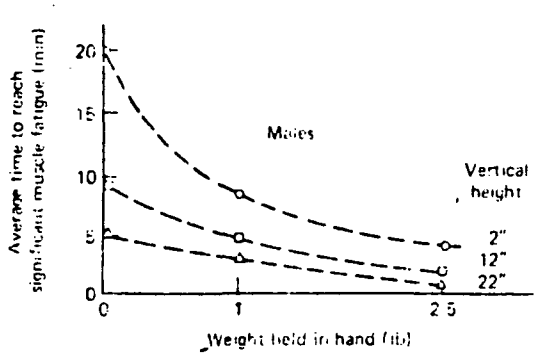
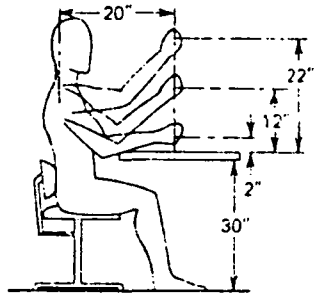
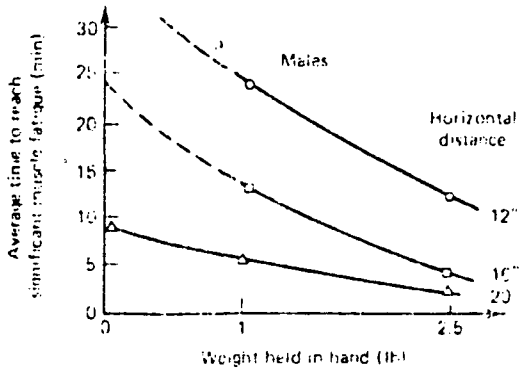

Easy Head Movement
Max Head Movement
30°
30°
30°
Max Eye Movement
Easy Eye Movement
Normal Sight Lines
Stand 10°
Sit 15°
30°
35°

DIAGRAM 1


Average time to reach significant muscle fatigue (min)
20
15
10
5
0
Males
Vertical height
2"
12"
22"
0
1
2.5
Weight held in hand (lb)


20"
22"
12"
2"
30"


Average time to reach significant muscle fatigue (min)
30
25
20
15
10
5
0
Males
Horizontal distance
12"
16"
20"
0
1
2.5
Weight held in hand (lb)

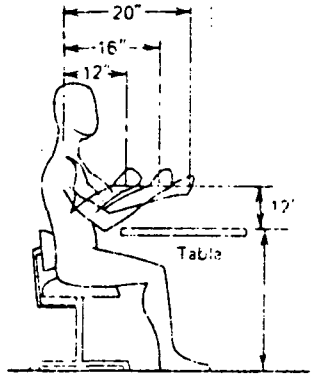
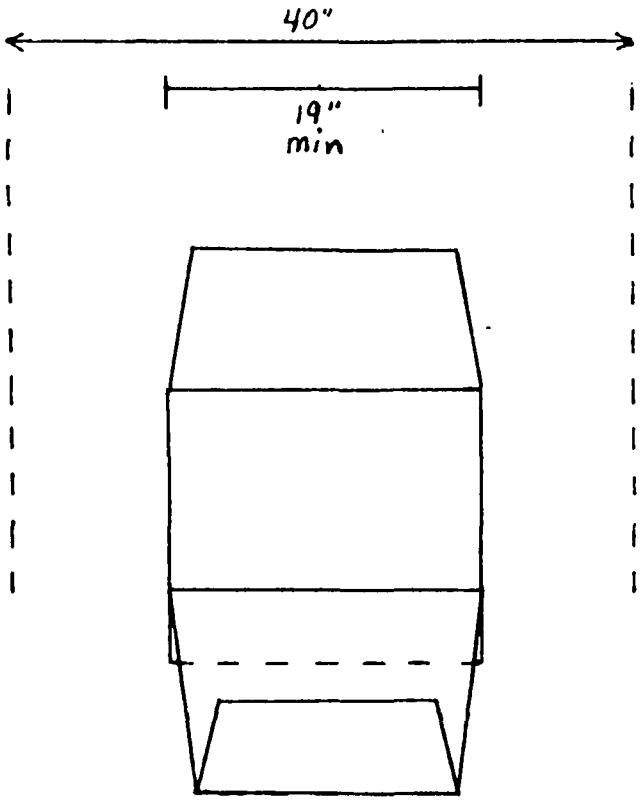

20"
16"
12"
12"
Table

DIAGRAM 2

PADDING DENSITY

Leg Support	None	–
Footrest	(None - nonskid surface)	
Seat Bottom	1"	Medium
Seat Back	1"	Soft
Headrest	1"	Soft
Lumbar Region	2"	Medium
Armrests (If used)	1"	Firm



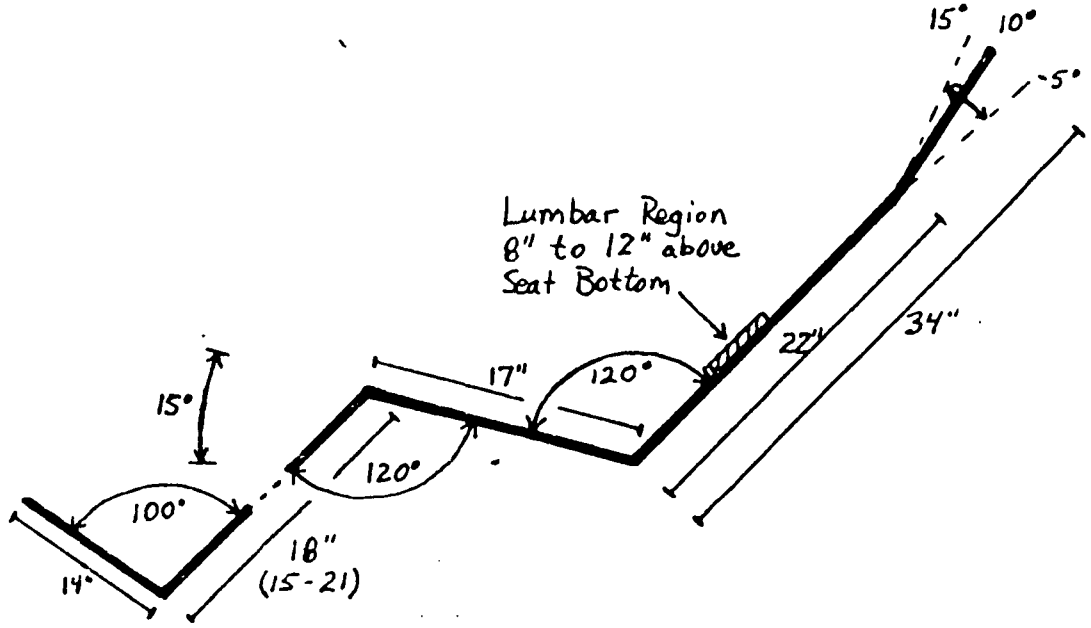
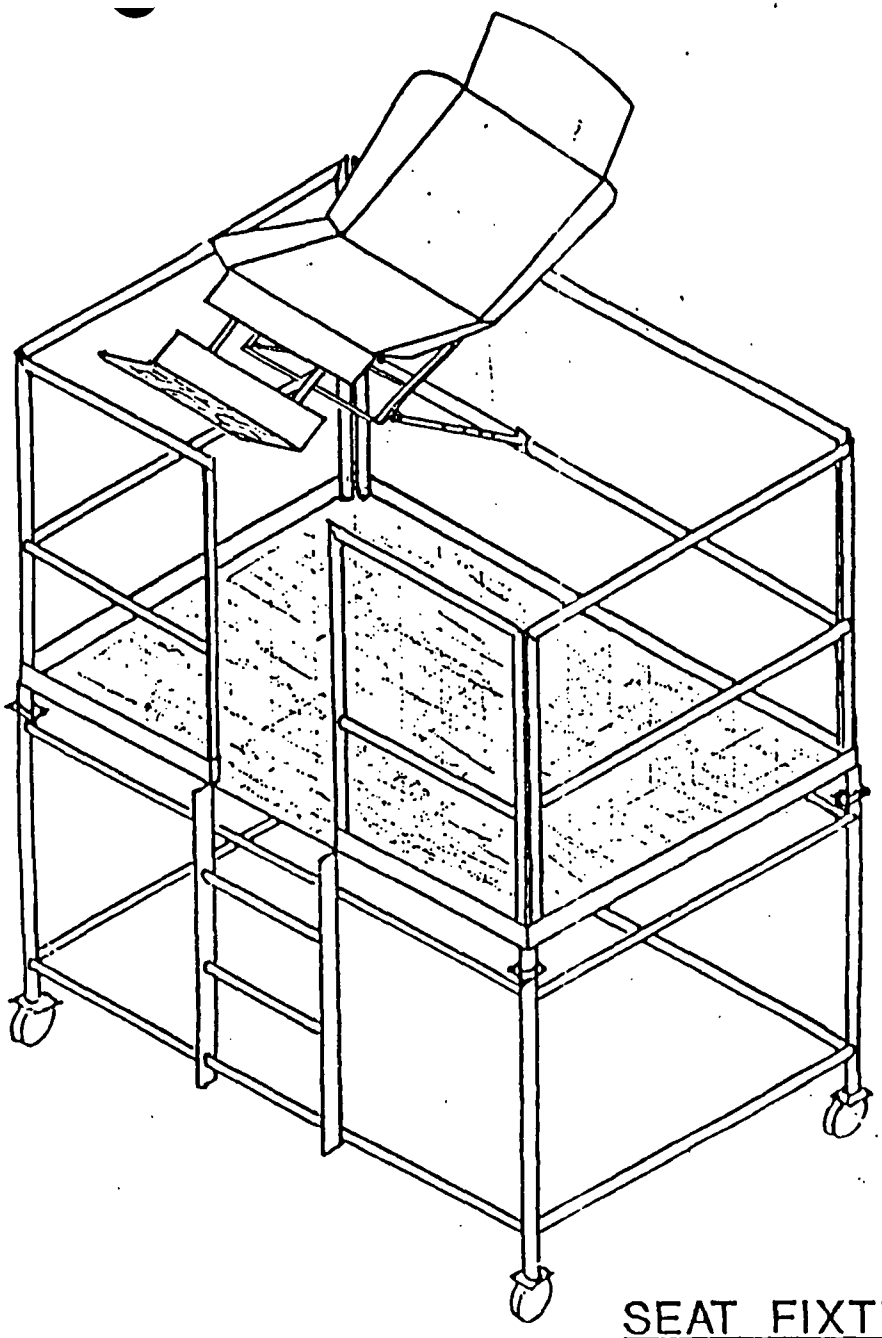


DIAGRAM 3



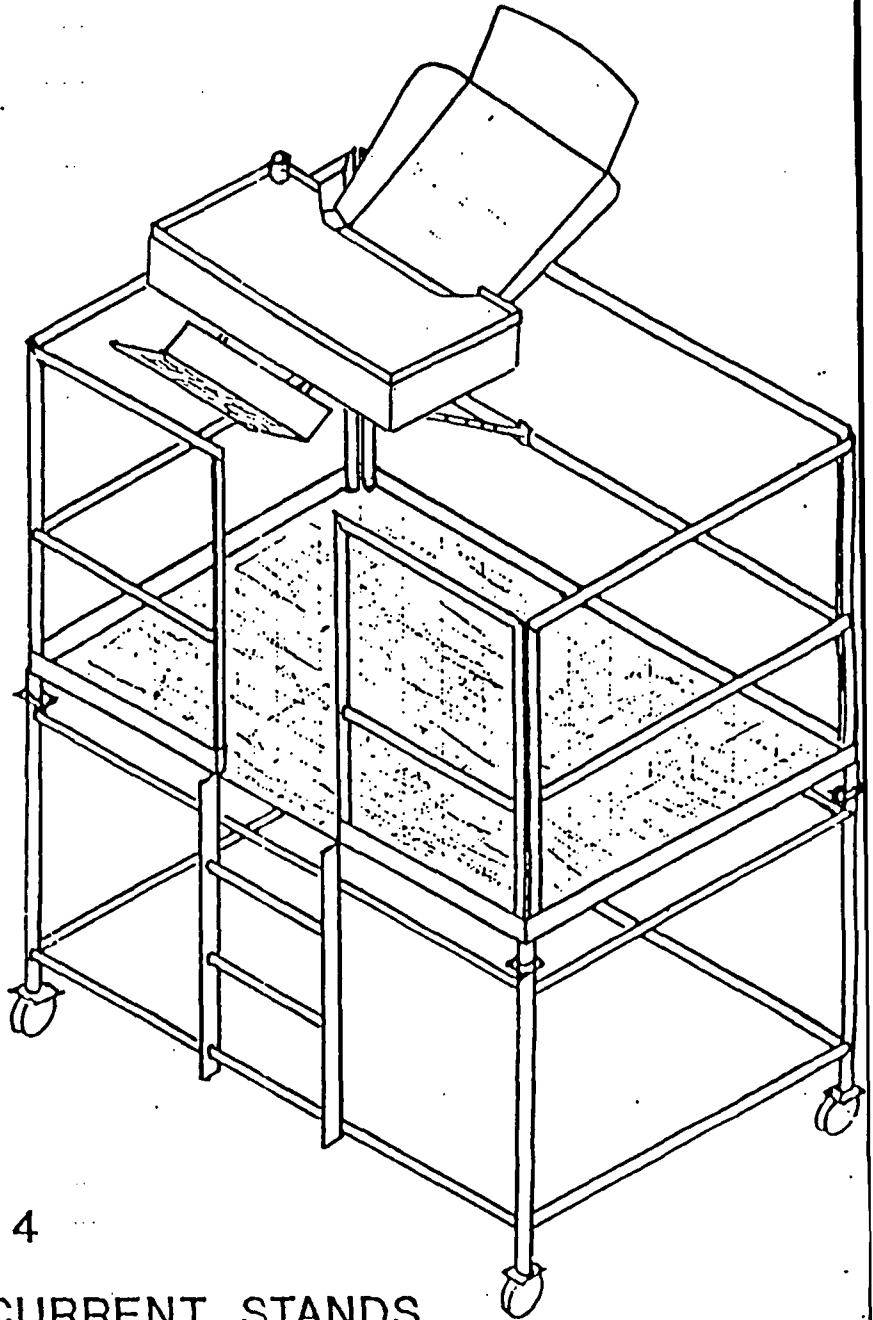


DIAGRAM 4

SEAT FIXTURE FOR CURRENT STANDS

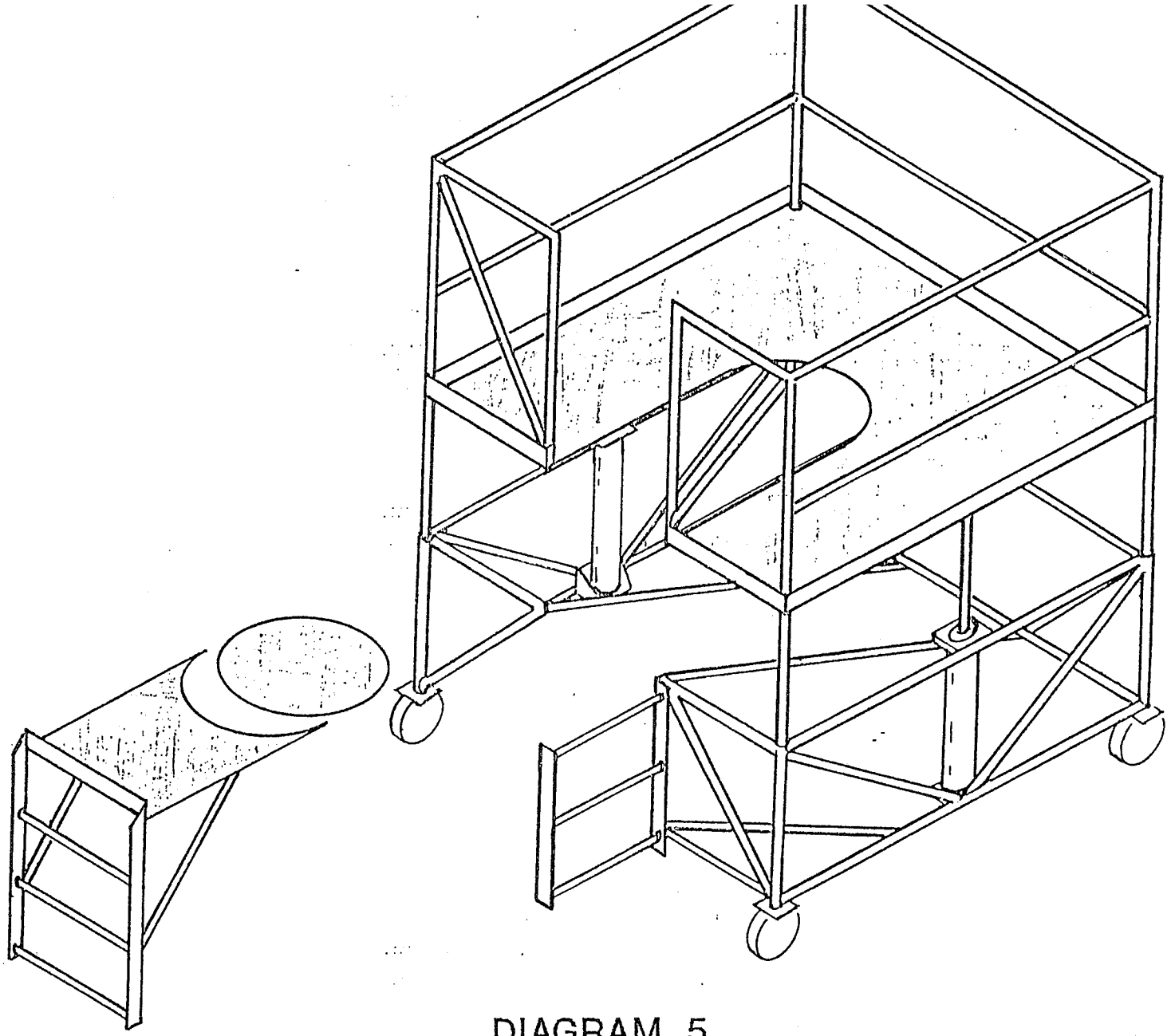


DIAGRAM 5

NEW DESIGN - ONE TO FOUR TECHNICIANS

Accommodates Bonding Tripod in Center

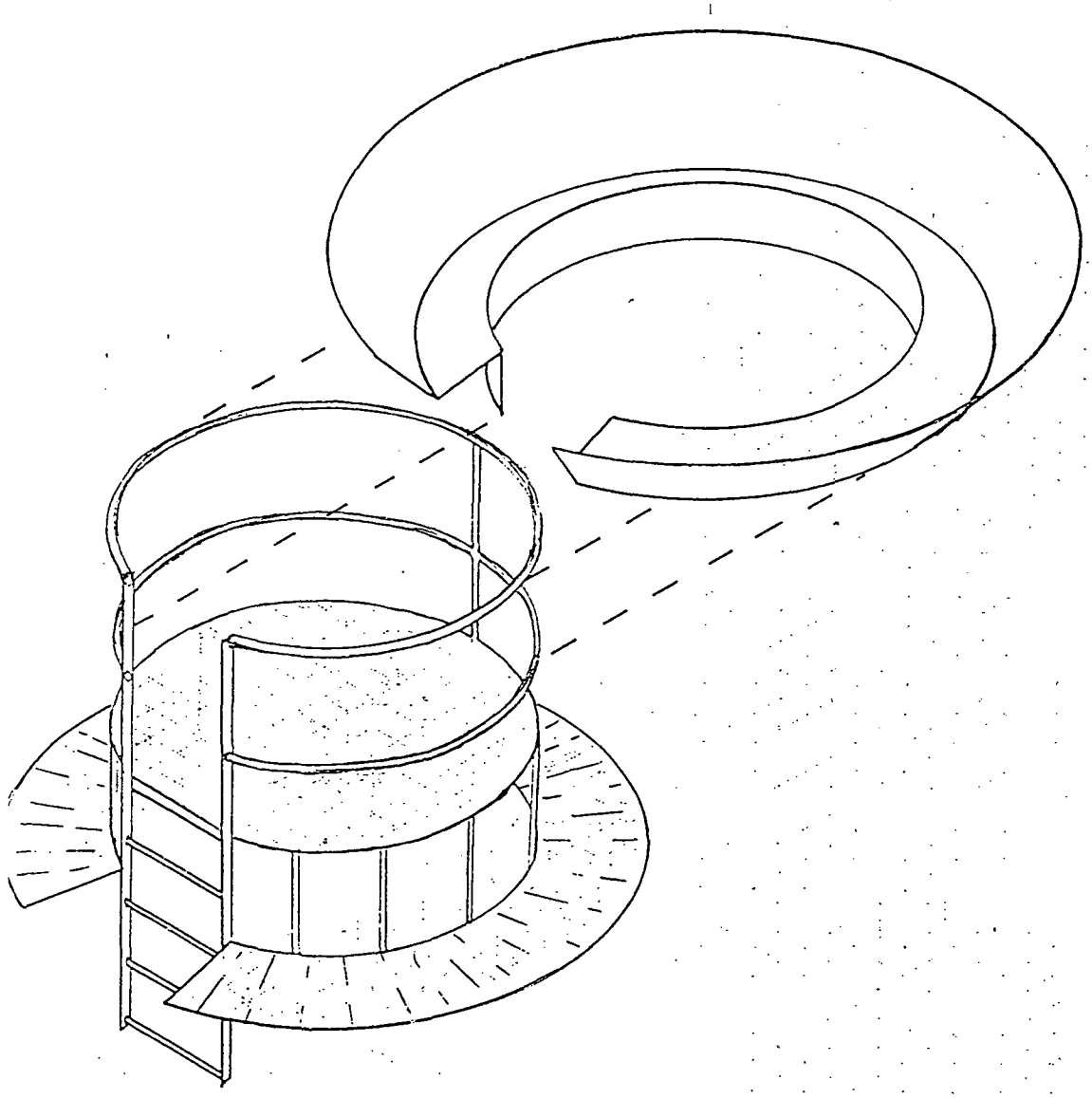


DIAGRAM 6

ALTERNATIVE 3: CIRCULAR WORK PLATFORM

Voice Data Entry

Interim Report

UNIVERSITY OF CENTRAL FLORIDA
ORLANDO, FLORIDA 32817

VOICE DATA ENTRY (VDE)
AT Kennedy Space Center (KSC)

Training and Implementation
Strategies for the Step and Gap Process (P-310)

Interim Report

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Tamim Hamid
John Scarboro

Department of Industrial Engineering and Management Systems

March 1990

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1.0 INTRODUCTION

The Tile Automation System (TAS) at Kennedy Space Center (KSC) includes the applications of automation, robotics and other advanced technologies to the shuttle Tile Processing System (TPS). The Voice Date Entry System (VDES) is one of the promising technologies currently being implemented. VDES is designed to replace the manual operations such as recording of large quantities of measurement data associated with the TPS. The system makes use of advances in the field of voice synthesis and recognition. It allows the technician to verbally input data directly into a computer. The technician is prompted by a speech synthesis module. The audio interaction between the computer and technician eliminates the need for a keyboard and video display during computer data input. The traditional computer input/output devices are replaced in the VDES by a portable headset containing a microphone and speaker.

There are a number of applications for the VDES in the TPS and other areas of KSC. Generally, it involves building, updating and retrieving information from computer databases. The first application of the VDES is in the step and gap measurement process (P-310) which is vital to the assurance of high quality for the TPS. In this process, tiles must be measured for step (differential between adjacent tiles) and gap (distance between tiles), when work is done that may alter these parameters such as tile replacement, tile removal and door and access panel opening. These measurements are made after any work, involving the tile, has been performed.

In a study to asses the benefits of the VDES, it was found that the time for the step and gap processing can be reduced from 173 minutes to 43 minutes per tile if VDE is used. The time savings result from the greatly reduced data entry and evaluation times. Those savings become even larger for larger sets of tiles due to the constant set up times associated with the VDES.

Other factors contributing to the improvement in the P-310 include:

1. The elimination of recording measurements on paper.
2. Enhancement of the accuracy and verification of data.
3. Reduction in the skill requirement associated with typing.
4. The VDES can be interfaced with automated measurement tools to decrease the required time for measurement.

Successful implementation of the VDES requires training of the system to recognize the user's voice as well as training the user to work with the system. This requires the development of a training and implementation strategies to insure acceptance of the system by its users, integrity and accuracy of data and give enough time for system testing.

The objective of this report is to present training and implementation strategies for VDES in support of P-310. (Appendix I is P-310 description.)

The training and implementation module presented in this report can easily be adapted to any new VDES applications, once the proper system is developed.

The report first provides a description of the systems hardware, software, capabilities and limitations. It then, introduces the training strategies for various levels of system users, to be followed by a suggested implementation strategy and general recommendations related to the use of the VDES in KSC operations.

2.0 SYSTEM DESCRIPTION

2.1 VDES and TPS Environment:

The application of the VDES in the TAS consists of three sections. Figure 1.0 is a schematic representation of these sections in the envisioned TAS processing cycle.

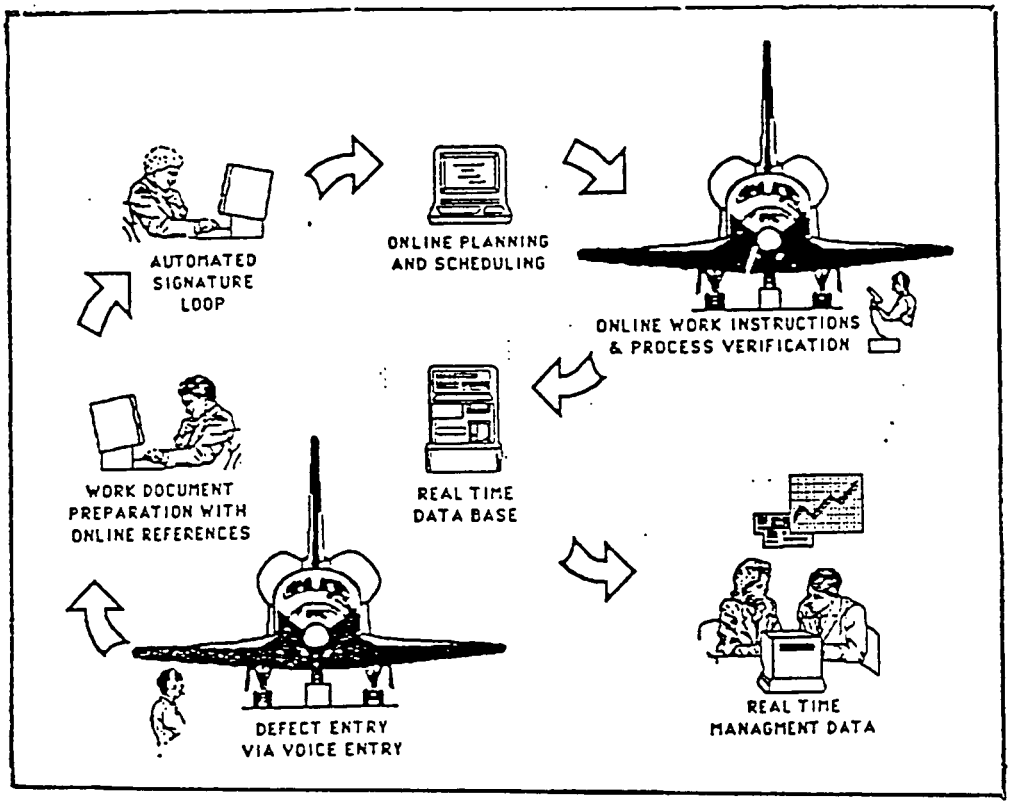

Figure 1. The Automation System and the VDES Applications

First, a TPS quality control technician inspects the thermal protection system after each flight using VDES to identify anomalies. The inspector voices in the part number, the extent of the anomaly and other necessary data which then produces an automated problem report in a central database. Second, the problem report is dispositioned by a TPS engineer using keyboard entry to identify the proper repair procedures for the particular anomaly. The problem report then proceeds through an electronic signature loop until final approval. Third, the TPS technician uses VDES to enter critical dimensions of step and gap measurements or P-310.

A workable module of VDES was developed to support P-310 in 1988 and its potential use is scheduled for 1990. A VDES is currently being designed for the Problem Report (PR) module. This module will enable a technician to describe problem reports by VDE. The primary benefit in this case will be the elimination of

PR's duplication. This has been a problem due to the lack of traceability of the current system.

Another area of potential VDE application is the Operating Maintenance Instruction (OMI), especially the non-standard repair module. Presently, a text to speech synthesizer is being investigated to produce process information for the technicians per OMI. This technology may also allow a quality inspector to verify work completed through the use of VDE.

The voice entry may have other applications in KSC where there is a need for computer human interaction involving data transfer in a fast manner with hands free environment. Possible areas of application are: warehousing, dispatching, and office operations.

2.2 Hardware Description and System Distribution :

Two kinds of computer systems are linked to serve the VDES. A DEC Micro VAX 3200 is on site at each hi-bay on the mezzanine level. Both MicroVAXes are linked by Ethernet to a DEC-VAX 8600 located remote from the hi-bays. DEC servers linked by RS 232 to the MicroVAXes are the interface between the MicroVAXes and the voice recognition and synthesis equipment. The voice synthesis equipment consists of DEC rack mounted DECTALK speech synthesis units. International Voice Products rack mounted model 4500 voice recognizer are currently used for voice recognition. The equipment currently is capable of handling eight users per hi-bay. Figure 2. is a schematic of the current hardware and its distribution. Figure 3. is the elements of the VDES for P-310.

Due to the rapid prototyping philosophy used in the implementation of VDE the hardware is subject to change as better alternatives are found by iterative testing of currently used hardware. The current voice data entry system at KSC consists of: input/ output interfaces, computer processors, voice synthesis and voice recognition hardware, and the associated cables and busses. The input/output devices are headphones with boom microphones. These may be replaced by in the ear microphone/ earphones in the future due to the possibility of more accurate recognition and increased durability. Presently the VDE system is networked via hardwire in the Orbiter Processing Facility (OPF). This presents problems with respect to safety and accessibility issues. The technicians have to manually route the connecting cables as needed depending on the location of their work. Therefore cabling strung out without proper tie down would create safety hazards for other persons and the wire could be damaged when tangled with other obstacles. Due to the scaffolding encompassing the shuttle, accessing certain regions of the shuttle requires unique positioning of the technicians workplace. To route the cables necessary to use a VDE system would require long amounts of cables, this would result in a proportional degradation in voice recognition. These problems were found

to be quite restrictive in incorporating a VDE system in an operational scenario, within the OPF.

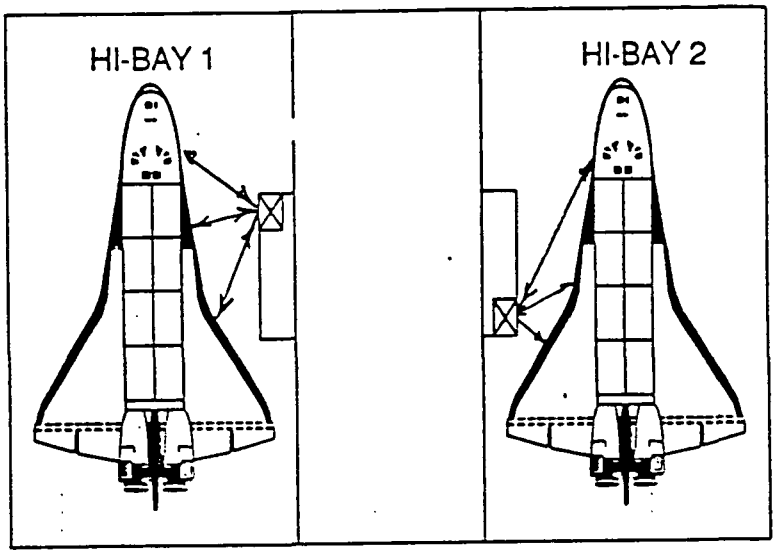

Figure 2. VDES Distribution in the Hi-Bays where P-S10 takes place

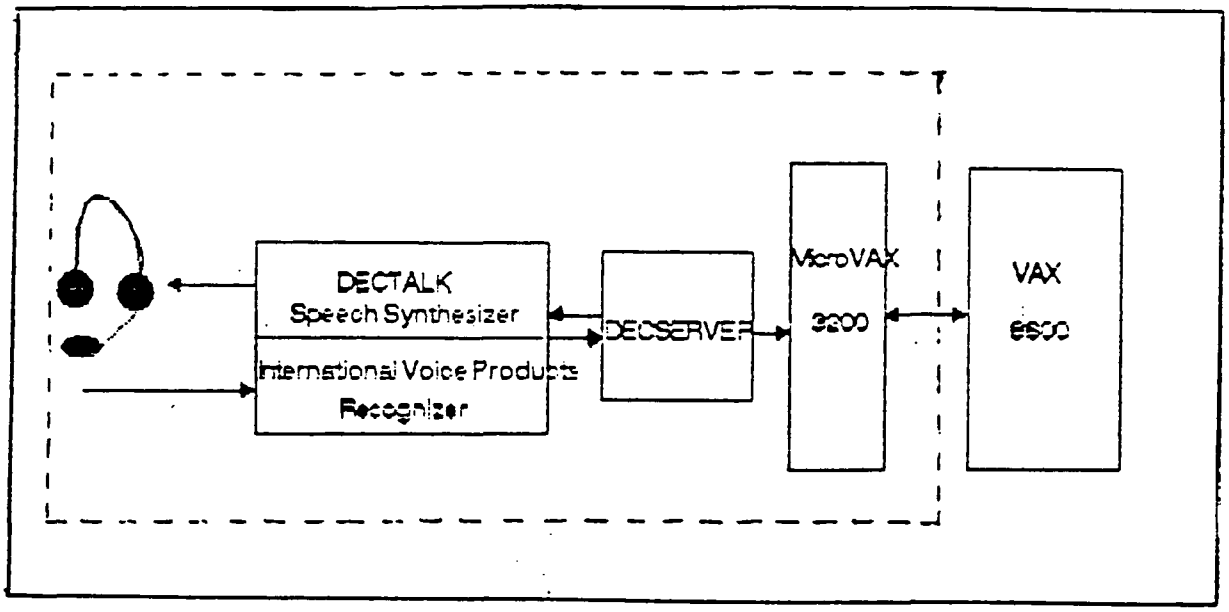

Figure 3. Elements of the VDES for P-310

The solution to this problem may be a Radio Frequency (RF) network possibly using digital voice transmission of VDE data. An RF system would alleviate the hardwire configuration that is present in the OPF, whereas problems discussed earlier would be eliminated. The foreseen problems, an RF system would initiate, can be in the areas of RF transmission and security issues. Since the shuttle is engulfed in a mold of metal scaffolding, 100% signal transmission could not be guaranteed at this time. Further analysis will be done on this subject. Security, with respect to Department Of Defense (DOD) missions in the OPF would be another roadblock to the acceptance of an RF signal in the OPF. The present procedure does not allow pagers, 2-way radios and other transmission devices to enter the OPF hi-bays, however technical cooperative meetings with NASA safety and security could be instrumental in the design phase of an RF module.

Currently, the IVP voice recognizer are being phased out in favor of Verbex units. The Verbex hardware will have significantly shorter times required to obtain usable voice patterns. This will affect the training in a positive manner as the new equipment should require about 4 hours less for the voice patterns than the current equipment. The anticipated reduction in training time is also affected by the software.

2.3 Software Description

Software generation for VDES application is a rapidly growing field. Creating the voice application necessary to effectively work in a VDES environment is limited by the application program. There are two types of software involved in all VDE systems:

1. The voice recognition and synthesis software--usually supplied by the system developer.

2. The main application program--developed by the user.

Data extracted through the application program is stored, in real time, in a relational database to be accessed and processed by the VDE software. The software that is contained within the VDE system is comprised of a grammar file, translation table and voice response sections. The applications software designed for P-310 is written in Ada programming language, which was selected for its excellence in portability, rich set of programming functions and tools, and a uniformity of code documentation. Ada also allows for multi-tasking which is critical for real-time processing. Multi-tasking has been an issue when multiple users are on line at any one given time. This problem will be addressed when applications for a VDE system will be dependent on the solution of multi-tasking problems. The P-310 application software is linked to a relational database. The software written for P-310, was in a specification format via Rockwell International. The conversion from specification and engineering format to code was achieved by creating a flowchart of the complete P-

310 process depicting points of voice prompt and data entry and the contents of exchanged messages. Therefore, when the software was validated and finally created the P-310 software automatically gave the appropriate decision statements. Presently the P-310 software is being converted into an IBM platform. This task was initiated by the Shuttle Processing Data Managerment System (SPDMS) group at Lockheed Space Operations. The SPDMS group has several automation projects they are projecting to incorporate into the OPF processing environment.

In a technical comparative study seeking other systems for the applications at KSC, the Verbex 5000 series was considered. The Verbex 5000 series recognizer offers up to a 800 word vocabulary, whereas the International Voice Product (IVP) recognizer only allow up to 100 words. Due to the restrictions imposed on the voice developer by the IVP software, the Verbex 5000 is now being investigated.

The VDES software available with Verbex has an extended vocabulary feature which allows for multiple vocabularies. In where each vocabulary may contain up to 80 words, shared among as many as 20 grammars, and there can be as many as 40 vocabularies in a single application. Depending on the design of the application program, a VDES system can have up to 3200 words. Whereas the IVP recognizer only allows up to 100 words of in a single application.

3.0 TRAINING STRATEGY

3.1 General

3.1.1 Target Population:

Work analysis for P-310 shows that potential users of the VDES are: Tile technicians, Quality Control Inspectors, Trainers for the system, and Supervisors and Managerial Personnel.

The way each one of these categories use the system is different from one another. A training strategy was developed for each category based on the way the system may be used. The numbers of expected trainees on the system for each category are:

Tile Technicians	150
Quality Inspectors	30
Trainers	10
Supervisors/Managers	28
Total	218

These figures represent all the personnel involved in tile operation, for all three shifts of orbiter TPS processing. Training all personnel on VDES is a recommended strategy for system acceptability by its users.

3.1.2. Training Environment:

The VDES at KSC uses speech synthesis, as the prompt and voice entry as the response. When executing a training pass, the speech synthesizer prompts the technician to say an utterance and the technician responds using voice data entry. The rejection/acceptance is controlled by a training supervisor (trainer) who monitors the training pass by listening to the trainee over a headset.

The technicians will be located in a simulated work environment similar to the OPF set up, whereas the training supervisor and the voice equipment are located in another adjacent room. Therefore, the technician has no access to a terminal for the training sequences, except for the 1st pass where a quiet environment is needed for proper training. The headset is hardwired to the voice equipment.

The International Voice Products VocaLink 4500 recognizer requires 3 passes of voice training. The vocabulary in this application consists of 96 words and takes about 2 hours per pass. Training takes place in a simulated quiet environment in the first pass and subsequent passes take place in the high-bay of the OPF.

The data that is to be used in the training scenarios is of alpha-numeric nature. The part numbers (tile numbers) contain both alphabetical and numeric information. The P-310 software also requires "yes," "no," "repeat," and other types of responses. The design of the P-310 VDES application software combination was to give maximum control textures for the technicians.

3.1.3 Strategy outline:

The strategy to be used in training potential users of the VDES is classified based on the user's categorization. For each category the report outline the strategy as follows:

1. Target Population: In this section the typical trainee in the category is identified.
2. Objectives: Specific objectives expected to be fulfilled if a trainee completed the training sessions.
3. Equipment and training aids: Necessary equipment and training aid required for the training scenarios.
4. Methodology: Detailing the set-up of the training sessions.
5. Procedure: Step-by-step description of the training session(s), procedure to follow, and the sequence of scenarios.
6. Measure of training effectiveness: The trial "test" measuring the accomplishments, by trainee to the objectives.

3.2 Strategies:

3.2.1 Strategy for TPS Technician and Quality Control (QC) Inspector

Target Population:

The target population for this training segment consists of TPS technicians with certifications 344 and 118, step and gap evaluation and step and gap measurement respectively. The QC aspect of this training will be identical to the TPS technician training with the exception of the actual certification number. For maximum benefit, the trainee should also be certified for laser tool step and gap measurement.

Objectives:

The objectives of this training are:

1. Introduce the technician to the VDES and its benefits.
2. Train the technician to set up and take down equipment.
3. Train the system to recognize the trainee voice.
4. To become familiar with the P-310 software.
5. To use the VDES to produce a computer generated P-310 report with no error under normal hi-bay conditions.

Equipment:

1. VDES equipment (hardware and software) to be used on the job.
   a. Voice recognition and Voice synthesis
   b. MicroVAX computer
   c. Headsets
2. P-310 software.
3. Technician training manual. (Appendix II)
4. Step and gap case studies. (Appendix III)

Methodology:

The training consists of five approximately two-hour segments to be given on different days over the span of two weeks. The first segment starts with an overall description of the system to introduce the technicians to the VDES and its benefits. The video tape for VDES developed by Lockheed International may be used as an introduction to the system. At the beginning of this session the trainee will be provided with a document containing system description, the benefits associated with using the system, the user vocabulary and the software. Except for the short introductory segment, the first three sessions will be used mainly to provide the system with voice patterns for the technician. These sessions will require a one-to-one technician to trainer ratio with the current voice recognition training software provided

with voice patterns for the technician. These sessions will require a one-to-one technician to trainer ratio with the current voice recognition training software provided by IVP. The fourth and fifth sessions will be used to train the technician on the use of the P-310 software and to fill out a P-310 report under normal working conditions. During these sessions the technician will be given a copy of the P-310 report to make notes as needed on several case studies. The case studies provide the same (Appendix III) information that would be available to the technician using the usual in the work environment such as step and gap measurements, tile numbers and spatial relations. One such method of providing this information would be to provide the technician with step and gap data maps for each case. The technician will then proceed to use the VDES in the hi-bay to generate P-310 reports for the case studies until they have completed three reports with no error.

Procedure:

Session One

1. Distribute the training manual and an introduction to the VDES and its benefits (verbal and or video introduction by trainer.)
2. Demonstrate the set up of the VDE equipment such as the headsets, and log on.
3. Take the first pass for the voice patterns in a quiet area.
4. Educate the technician on proper speaking habits for a VDES system.
5. Demonstrate the take down procedures for the VDE equipment such as return of headsets and log off.

Session Two

1. Have the technician set up equipment such as arranging the headset and logging on.
2. Demonstrate cable placement and hook up in the hi-bay.
3. Take the second pass for the voice patterns in the hi-bay.
4. Demonstrate cable unhooking procedures.
5. Have the technician log off and put up headphones.

Session Three

1. Have the technician set up the VDE equipment for use in the hi-bay.
2. Take the third pass for the voice patterns in the hi-bay.
3. Have the technician remove equipment from the hi-bay and log off.

Sessions Four and Five:

1. Provide the technician with a copy of the P-310 report and case studies. Appendix III contains case study scenarios. Explain that the case studies are to be used as if they were actual information to be entered on the job and that completing three with no errors will conclude the training.
2. Have the technician set up the VDE equipment for use in the hi-bay.
3. Have the technician practice entering the case study information until three case studies have been entered correctly.
4. One such case study may involve entering data while performing the measurement (Manually or using the laser tool.)
5. Have the technician remove equipment from the hi-bay and log off.
6. Show QC a final printout of P-310 from the evaluation techniques used by the software in order to conclude to a particular decision.

This training scenarios should provide the TPS and QC technicians with a sufficient understanding of the VDES and P-310 software to incorporate these items into their work. The TPS technician should be able to be proficient in using the VDES for step and gap data entry. The QC inspector should be able to assure the integrity of the step and gap data with the understanding of the system.

Measure of proficiency:

- Successful set up of the system without trainer interference
- Completeness of three P-310 reports with no errors.
- High Confidence level of system performance.

3.2.2. Strategy for VDES Trainer

Target Population:

The target population consists of the trainers and training specialists for the TPS who are involved in the VDES training. It is recommended that the trainer has an engineering background and familiarity with TPS and its operations.

Objectives:

1. Prepare the trainers to run the segments of the VDES system required for the training sessions for various target populations.
2. Familiarize and train the trainers on the use of training aids associated with various strategies.

3. Prepare the trainers to get feedback on current training techniques, system implementation and other areas where there may be the possibility of improvements.

Equipment & Training Aids:

1. VDES and keyboard entry system.
2. VDES computer training software.
3. Engineer who is familiar with the system.
4. Training documents for all trainee categories.

Methodology:

The preparation of the trainer should be performed by a process technology engineer who is familiar with the system. There is only one trainer planned to be involved with the VDES training at a time, so the training session could be intensive with relatively little time allocation on the part of the trainer or the process technology engineer. The program should stress a "hands on" approach for maximal training retention. All case studies and all sessions for all categories should be included for practice with the system.

The trainers should first complete the TPS technician and QC inspector training modules, before trained for the managerial training module. This sequence will assure that the trainer has a sufficient understanding of the system to fully appreciate its benefits and use.

Procedure:

The TPS technician and QC training session should proceed as follows:

1. Give a short description of the system. The equipment technical manuals could be used in this description..
2. Explain to the technician and QC how VDE will integrate and change present methods of entering data.
3. Demonstrate the system use to the trainer using standard system test.
4. Train the trainer to use the system using P-310 application program. During training emphasize points that the trainer should be especially aware of. This will be the first coverage of necessary training techniques. Use technician training module where appropriate. Perhaps a smaller vocabulary will be sufficient and will save time.
5. Review training strategies (modules) and case studies for technicians and quality inspectors.
6. Demonstrate set up the system for training purposes.
7. Have the trainer set up the system for training.
8. Have the trainer perform all case studies.
9. Cover the required steps for training a technician and QC inspector.
10. Have the trainer set up the system for training and train a technician.

11. Review training strategies for supervisor and managerial personnel.
12. Conduct a dry run for supervisors strategy.

3.2.3 Strategy for Managerial Personnel

Target Population:

This training script is designed for KSC department managers and supervisors who may be potential user/beneficiary of a VDES for operations in his/her department.

Objectives:

1. Familiarize managers with the VDES system.
2. Give managers an appreciation of the system benefits.
3. Get feedback about other areas in KSC operations where a VDE system may be used.

Equipment & Training Aids:

1. Slides of potential benefits and areas of highest impact. (Appendix IV-A)
2. VDE and keyboard entry system or simulator.
3. Slide projection for the equipment in use. (Appendix IV-B)
4. Engineer who is familiar with the system.

Methodology:

The training sessions should be held with 5 to 6 managers of the same level to allow peer interaction as well as as actual experimentation with the system, with discussion encouraged. The duration of this session should be for 2 hours with ten minutes break after the first hour. The first hour is presentation. The second hour is for trainees who may want to experiment with the system. Highlights of the verbal presentation should be provided to the trainees in note form. (i.e. copies of the presentation Appendix IV should be provided to participants.)

Procedure:

1. Have an engineer who is familiar with the VDE and the thermal protection systems give a short introduction.
2. Use a slide presentation to provide the trainees with an appreciation to the VDES and its savings in: time, cost, personnel, skill requirement, and automation. The trainer may provoke feedback for other applications at this point and during the experimentation with the system.
3. Demonstrate the difference in time required to input data by keyboard versus VDE. Encourage trainees to try the system. This is to be

accomplished using a simulated case where some of the trainees would experiment with the system (in the second hour).

4. Provide trainees with a package system information, benefits and a return form for further communication and possible use.
5. Explain difference between VDE and application program. This is important since the two are separate entities of each other, and should be well explained.

After the training session the trainees should be familiar with the benefits of, and be motivated to look for other applications for VDE. This motivation and understanding should make the actual implementation of the system smoother through increased cooperation and participation of management in VDES implementation.

4.0 IMPLEMENTATION STRATEGY

4.1 General

There are three types of strategies for introducing new technologies to an existing system. Cut-off, Gradual and Parallel. These along with a "combination method" proposed for the implementation of the VDES in P-310 will be discussed in this section.

1) Cut-off: The cut-off method consists of shutting down an old method and replacing it with the new based on a preset date for implementation estimated theoretically. Figure 4.A is a graphical representation of the cut-off strategy.

There are several reasons why this method is considered a high risk method for VDES application in P-310. Unexpected events such as software error, hardware failure or insufficient training for technician can occur after the new system has been installed. Such events, in the absence of a backup system could result in non-recording of tile data and loss of traceability of recorded data.

Secondly, the new system, once implemented will become the main system, conversion from old to new could result in loss of critical data recorded using old system. The cut-off method would not be a viable strategy for any KSC application in general and that of P-310 in particular.

2) Gradual: The gradual method as its name implies is basically decreasing the old technology while at the same time, increasing the new technology. Figure 4.B is a graphical representation of the gradual strategy.

As more personnel are trained on the VDES and start using it, the percentage of old method use decreases accordingly. This method eventually delivers the new technology over a given period of time at full use. This method would be ideal if the confidence in the operability of the new system is high. The psychological advantage in this strategy is that it will allow the new users to break the "acceptance barrier" in the environment which is one of the most critical phases of these methods. In this strategy, data for step & gap will be recorded only once, either using VDES or the current manual procedure. It has the advantage of no duplication for the effort, however, it takes longer implementation time and it may make traceability of data difficult.

3) Parallel: The parallel method simply says you do not throw away the old method until you are sure the new one is working. Figure 4.C is a graphical representation of the parallel implementation strategy.

In the P-310 application, it means use the VDES along with the manual and record data twice, once using the current manual procedure, and another using VDES, compare recorded data, verify whichever is in error and correct the VDES if it is the

one in error. This method gives the whole system a great amount of flexibility with 2high cost.

The VDES output can be used immediately, but still having the option to convert back to the old technology at any time. This eventually will allow the total replacement of the old method, after enough time has passed to insure the integrity of data recorded (entered) using VDES. The disadvantage of this strategy is that KSC would be running two systems with all its associated costs and resistance to change on the part of the technicians. Its advantage is that it allows sufficient time for testing the VDES system and to train sufficient technicians and QC inspectors.

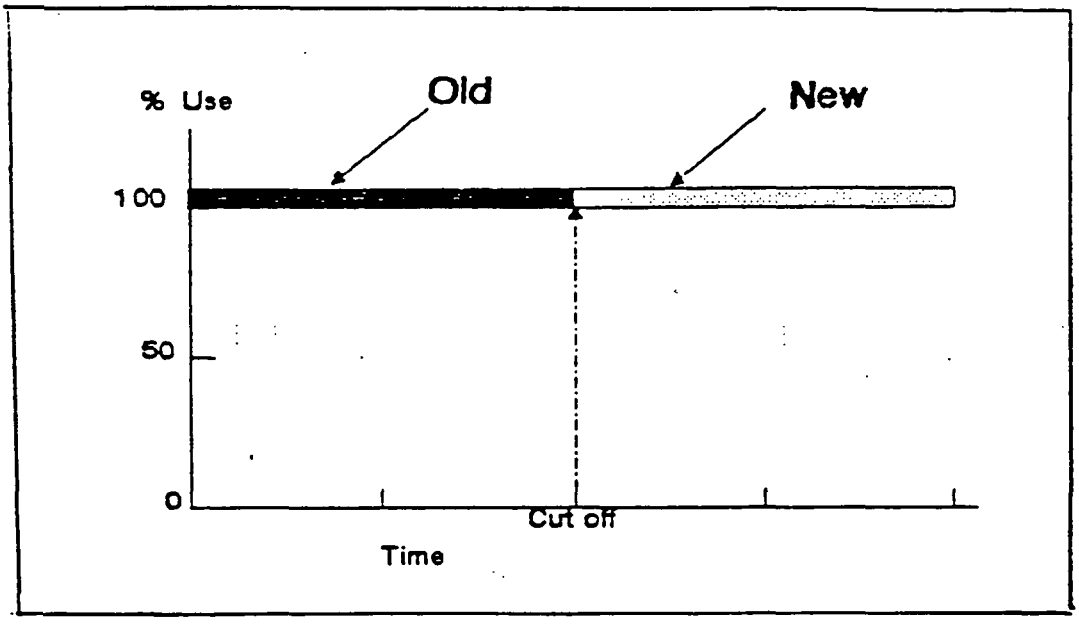

Figure 4.A Cut-off Strategy.

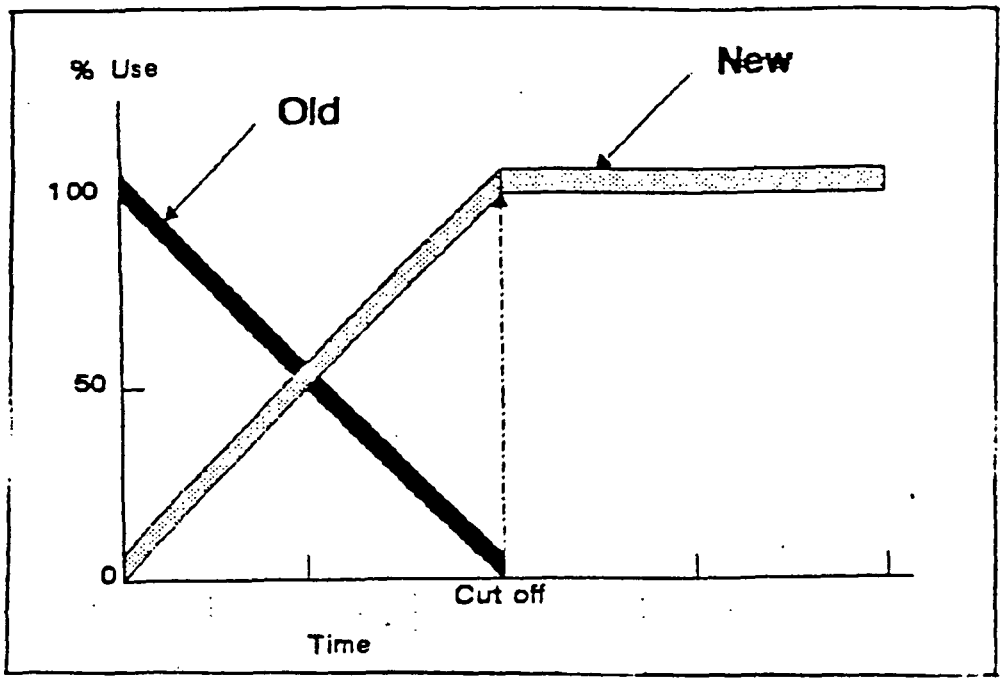

Figure 4.B Gradual Implementation.

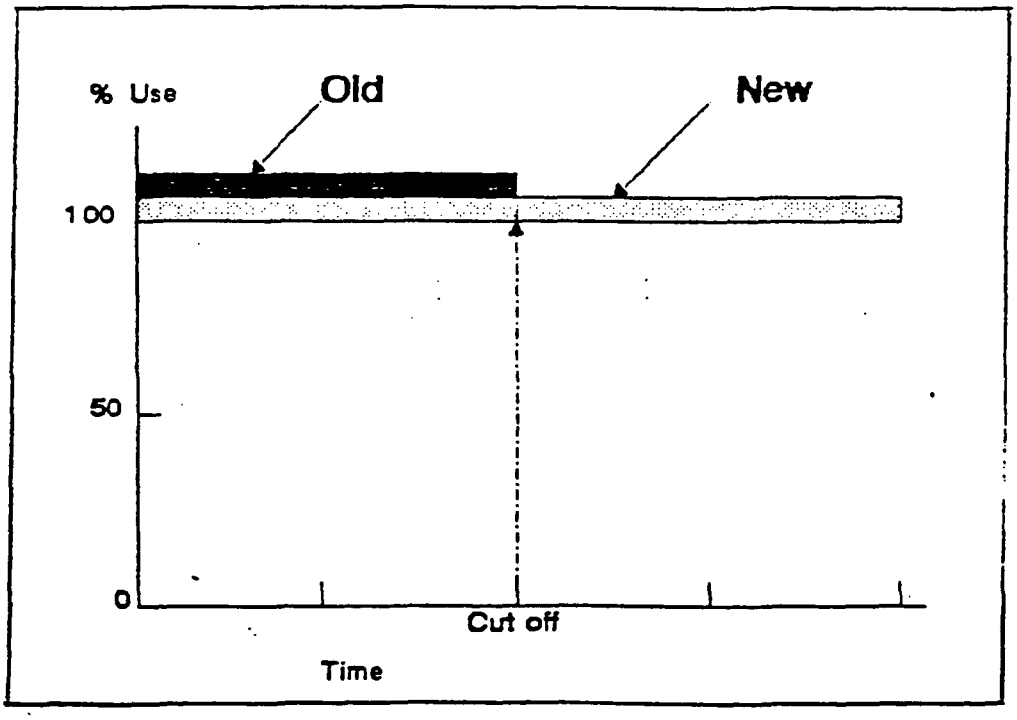

Figure 4.C Parallel Implementation.

4.2 Selected Strategy:

Based on the analysis of the situation, we propose a combination of gradual and parallel methods for the KSC, P-310 operation. This method will be called Parallel/Gradual strategy combination. A parallel implementation plan will be initiated for four flows after training half the target population in the technicians and QC inspectors categories to be followed by the gradual implementation over 3 to 4 flows before cut-off of present system. Figure 5. is a graphical representation of the recommended strategy.

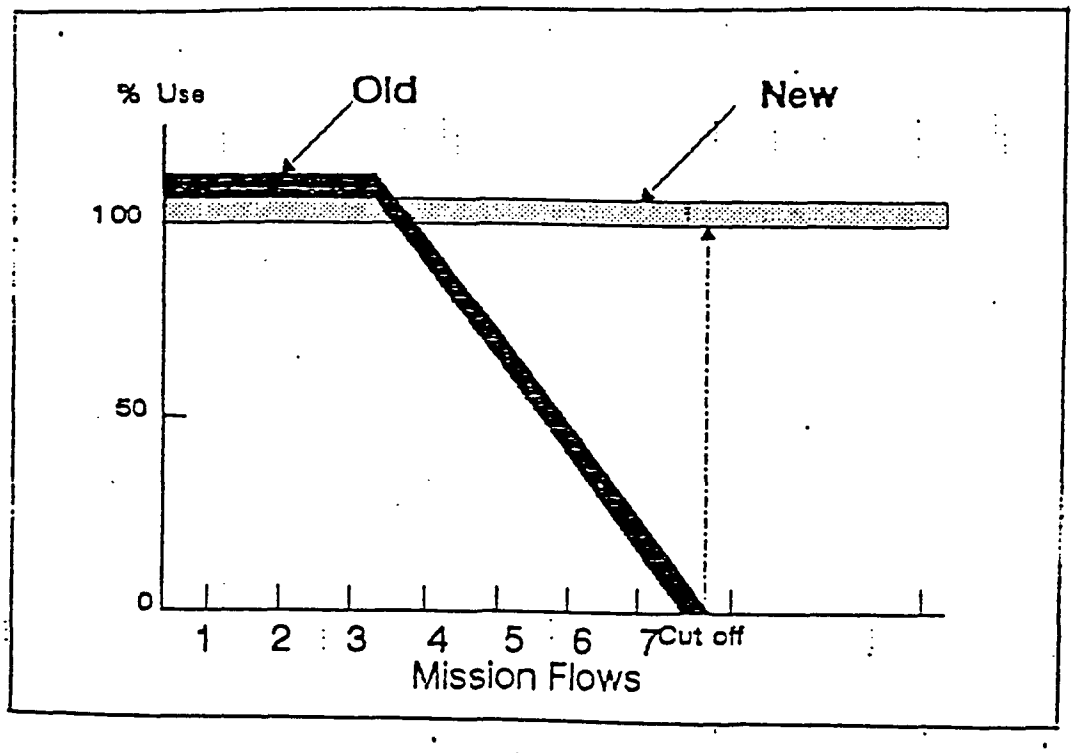

Figure 5. Parallel/gradual Implementation.

Justification for this strategy is motivated by the following:

1. Although the current P-310 application software is fully certified and validated it has not been tested in the operational environment thoroughly.
2. Problems associated with non hardwire communication have not been resolved yet.
3. Parallel implementation for 4 flows will allow on "the job" testing of the system and training of system users.

4. It is recommended that system developers use the parallel plan of the strategy to compare data recorded by both systems and make the necessary corrections in the P-310 application software.
5. The gradual phase of the strategy will allow other potential users the opportunity to appreciate the benefits of the system and break the psychological barrier associated with introduction of new technologies.
6. A period of 7 to 8 flows may allow time for new system being investigated by UCF.

5.0 RECOMMENDATIONS

5.1 VDES Training:

1. Training strategies recommended in Section 3.0 of this document should be followed as presented.

2. Certify current technicians and Quality Control inspectors for VDES at the end of successful training as recommended in each category.

3. Certify incoming technicians on VDES in lieu of manual operations, once the system is commissioned for use at KSC.

4. Trainers involved in the VDES training need to be updated on any new hardware and/or software addition and/or modification. Training strategies need to be modified accordingly.

5. Collect and/or document any data related to the training, and use the data to enhance the recommended strategies as well as anticipated VDES applications at KSC.

6. Initial trainers selection should be carefully contemplated, since the attitude of trainers is proportional to integration of a VDE system. Trainer with good spirits and good understanding is critical in incorporating such a system.

7. Publish and disseminate training experiences to other agencies and/or NASA-KSC subcontractors for possible use of such experience.

5.2 VDES Implementation:

1. Parallel/gradual combination strategy for the VDES.

2. Parallel implementation of the VDES to the current manual system for P-310 for 4 mission flows.

3. Monitor system performance during the parallel phase, and rectify/correct the P-310 application software via Problem Reports.

4. Training of more users takes place during the parallel and gradual phases of the recommended strategy.

5. Gradual implementation for 4 to 5 missions flows before cut-off.

6. Replace the manual data recording through keyboarding by the VDES procedure.

7. Redesign the data map to reflect any changes mandated by the VDES use by reformatting the specifications called out by MLO601-0001 of Rockwell International.

5.3 General System:

This section of the recommendation is a by-product of the study. They relate to systems hardware, software, system configuration and use.

1. Study the feasibility of using more diversified microcomputer based systems.

2. Study the feasibility of a Radio Frequency (RF) Network as a means of communication between the user and the VDES.

3. New system should be able to communicate with the current NASA-KSC main frame (IBM 3090).

4. We emphasize the need for maintaining standards throughout the design and implementation phases of the VDE applications.

5. System should be able to communicate with any platform that is operational in the KSC area.

6. Establish strong communication link with the Shuttle Processing Data Management System (SPDMS II), both from the hardware and software point of view.

7. The VDE system which resides in the mezzanine of each hi-bay of the OPF is quite adequate due to the limitations of available workspace in the OPF. The system configuration will require additional research since ergonomics considerations are at hand. Therefore, UCF will conduct a study on the proceedings of P-310 operations and review this topic in the following interim report.

Appendices

I. P-310 Description
II. Technician Training Manual
III. Step and Gap Case Studies
IV. Managerial/Supervisors Training Aids
    A. VDES Benefits and Areas of High Impact
    B. Equipment use

Appendix I

Process (P-310) Description
(Step and Gap)

Appendix I

Process (P-310) Description
(Step and Gap)

The step and gap measurements that is obtained by the technicians, is called out by a specifications created by Rockwell International. These measurements are taken when a tile either has been removed and replaced, engineering analysis requires step and gap data, or damages to tiles might require step and gap measurements in order to insure criteria have not been changed especially in high-temperature areas of the orbiter. The manual method of attaining the step and gap measurements involves the following procedures:

1. Technician (118 certification) acquires proper tooling to measure the step and gap (Trammel, Shims, Corner tool, Laser sensor).

2. After Measurements have been taken, technician then fills out a P-310 Process Control Record (PCR), which is basically a matrix of the specification (MLO601-0001), which contains the gathered data.

3. Depending on the situation, sometimes a data sheet with a data map, containing multiple tiles are completed by technicians. If an individual tile is being measured then four sets of drawings is required for each tile.

4. Data is then evaluated with reference to the MLO601-001 specification document by the technician (344 certification).

5. Quality Control personnel then verifies that evaluation is complete and any rework or unacceptable condition is documented.

6. NASA Quality Assurance confirms that the data complies with the specification requirements.

7. Document is then submitted to the TAIR station for filing and distribution through OPF operations (planning, shop and engineering).

Attached to this report is a complete copy of the MLO601-9024 specification on final step and gap inspection.

Appendix II
Technician Training Manual

1. System Description
2. Benefits associated with using the system
3. User vocabulary
4. Software Description

APPENDIX II
TECHNICIAN TRAINING MANUAL

1. System Description

The Step and Gap program was produced in an effort to reduce the time and effort spent evaluating MLO601-9024 Process 310 - Final Step and Gap Inspection. It will take data entered by a technician on the OPF floor and evaluate it using the criteria in MLO601-001. The program will work in either of two data entry modes: Keyboard data entry or Voice data entry.

The result of either of these modes is a computer generated P-310 report. It resembles the existing manual PCR with the exception that the computer does not produce a drawing of the tile. Instead the tile to tile intersections and the step, gap, and where appropriate the thermal barrier recession/protrusion are printed.

2. Benefits associated with using the system

The benefits that are associated with VDES are in the areas of accuracy and verification of data, reduction of time, alleviation of skill requirements for technicians, the VDE system can interface with other automated tools such as the step and gap laser sensor, the barcoding paper tracking system and the automated planning and scheduling effort.

Accuracy and verification of data: The ability to directly input real-time data and having the capability of instantaneously evaluating the data, is highly advantageous. The present method of transferring data between documents and personnel would contribute to a considerable amount of error. The person that has taken the measurements does not sometimes perform the evaluation on that particular tile. The ability to verify data en a VDE system with voice output guarantees the user that data are correctly entered.

Reduction of time: Presently the evaluation period takes between 2 to 3 hours for a P-310 to be accomplished for one tile. VDE allows a user to input a mid-point and a corner step and gap, and produce a P-310 form in less than 15 minutes, that is, fully evaluated and printed. Such savings in time contribute highly to the productivity of the TPS in addition to large decrease in the paperwork traditionally required for P-310.

Alleviation of skill requirements for technicians: The amount of training required for a TPS technician is around 1500 hours. This time is spent on OJT (On the Job Training) with other fully qualified technicians. The technician needs two certifications in order to completely fill out the P-310 document: 118 and 344 certification. A 118 certification allows the technician to measure per specification. Whereas the 344 certification certifies that a technician can successfully evaluate a particular situation

particular situation per MLO601-0001 specification. The complexity of evaluating a tile involves experience and knowledge of the Thermal Protection System.

The VDE system is viable and accurate enough to allow an inputter with a 118 certification to successfully complete a P-310 form fully evaluated. This greatly reduces the amount of hours needed to train for a 344 certification.

The VDE system replaces the conventional rubber stamping method with a security minded sole user system. A computer record contains time started and completed, tile part number, out of tolerance, different tools utilized as well as other pertinent data is maintained within the system therefore having the ability to perform analysis studies and further improvement to the system.

3. User vocabulary

The following words are in the P-310 vocabulary which the user needs to train the system for it:

cancel	1	part number
help	2	hello
repeat message	3	paul
alpha	4	betty
bravo	5	harry
charlie	6	frank
delta	7	brat
echo	8	rita
foxtrot	9	ursula
golf	0	dennis
hotel	dash	wendy
india	minus	vertical
juliet	open	forward
kilo	yes	mid
lima	no	aft
mike	number	rightwing
november	enter	leftwing
oscar	ames	RCC
papa	partial ames	FRSI
quebec	pillow gap filler	FIB
romeo	installed	rightpod
sierra	captive gap filler	leftpod
tango	thermal barrier	
uniform	empty	
victor	laser	
whiskey	corner	
x-ray	trammel	
yankee	shims	
zulu	payload bay door	

4. Software Description

Running the STEP And GAP program:

First you must locate the terminal and printer being used for this process. Sit down at the terminal and log on (your training class should go over this in detail). Simply use the following steps. First roll the mouse across the table.

1. create a VT220 screen using the mouse
   position the cursor by moving the mouse
   press the leftmost mouse button
   choose "Create new VT220 window" with the mouse
   press the leftmost mouse button again.

2. you will see: Username:

3. enter the account name Username:_____
   (the account name is TAS USER)

4. You will now be logged on

5. the following screen will be displayed:

   Employee Number: _____
   Password: _____

Laser Tool: _____
Laser Tool Port Name: _____
Error Protocol:_____

Voice Port Number___
Download needed:____
Verify Template Download:___

7. enter your employee number — Employee number:_____

8. enter your password — Password:_____
   the training coord. sets this up

9. are you using a laser tool: — Laser Tool:_____
   enter N for no, Y for yes and answer

   a. enter the laser tool port name: — Laser Tool Port Name:____
      it is in for form LTA9XX where XX
      is a number from 01 to 15

   b. does the laser tool use error detection: Error Protocol:____

enter N for No, Y for Yes

10. What voice port number will you use: Voice Port Number:___
if not using voice data entry just hit return
otherwise the numbers are from 1 to 15

a. are your voice patterns already loaded: Download needed:____
enter Y to download, N to skip

b. check for error messages: Verify Template Download:_
enter Y if no errors, N otherwise

Congratulations. You are now running the program. First you must select what kind of evaluation you want. You will see a screen of information like this:

STEP AND GAP MENU

1. Run step and gap program
2. Evaluate a single mid point
3. Evaluate a single corner
4. Print out a PCR or evaluation sheet

Z. Exit program and log off

To choose one of the programs use the arrow keys to highlight the selection you want and press the return key. At first you will want only selection number 1 to run the program and the Z selection to exit. Later you may wish to use selection number four to print out a PCR you've already evaluated.

The program works by having screens of questions completed. Look the screen over. It has a heading line at the top and a prompt line at the bottom. The program "asks" questions at the prompt line. You will answer them by filing in the screen. The cursor is located where the data you enter will be displayed.

It is essential that this information be completed correctly for the Step and Gap program to produce a correct evaluation.

STEP AND GAP HEADER INPUT

WAD NO._____ VEH NO _____ NUMBER OF TILES_____

STEP STOOL TYPE		Z NUMBER	CALIBRATION DUE
LASER	(Y/N)	_____	_____
CORNER STEP	(Y/N)	_____	_____
TRAMMEL	(Y/N)	_____	_____
SHIMS	(Y/N)	_____	_____

PART NO. V070-_____

OCN NO. _____

NUMBER OF MID POINTS: _____

CORNER STEP AND GAP REQUIRED?_____

NUMBER OF CORNER MEASUREMENTS:_____

AREA:_____ VERIFY COMPLETE:_____

The first screen is the WAD initialization screen.

WAD NO: Enter the WAD number at this point. To exit the program and log off the system type EXIT here. This will insure that no other person can use your password.'

VEH NO: The vehicle number will be used if it is supplied in the WAD Number. Otherwise enter one of the orbiter numbers here.

NUMBER OF TILES: Many tiles may be processed under one WAD Number. This is where you tell how many tiles you will be evaluating with the same WAD Number.

STEP TOOL TYPE: Enter a U (for yes) for all tools used for step measurements in mid point and corner evaluations. Enter a N (for no) if the tool was not used for step measurements. Then enter the tools Z number and calibration date. The date is in the format: MM-dd-yy. Using this format February 13, 1989 is entered as 2-13-89.

PART NO. Next you have to enter those impossible to read part numbers. Notice that VO70- is already provided for the part number so that you never have to type it in.

OCN NO. Enter the OCN Number.

NUMBER OF MID POINTS: Count the number of mid points on the tile to evaluate and enter that number.

CORNER STEP AND GAP REQUIRED? If you are also doing a Corner Step P-310 enter a Y to indicate it was required. Enter a N if no corner step and gap is required.

AREA: This is the Region A roughness zone (it can be found in MLO601-0001). It is a number from 1 to 6. The only tricky thing here is if the tile is on a roughness zone boundary, you should enter the smaller number of the two zones (the MLO601-0001 calls out for this). Please enter this number correctly, because it affects the evaluation.

VERIFY COMPLETE: This question assures that the last entry was correct, before the calculation is completed. Verify one last time that the data is correct and enter a Y if it is. Enter a N otherwise and use the cancel key (the) key on the numeric keypad) to correct the error. This question will be the last question asked for each part number.

MID POINT INITIALIZATION

PART NO: _____ CAVITY DWG NUMBER: _____ LOCATION CODE: __

TILE TO TILE INTERSECTIONS	CAVITY DWG NUMBER	DESIGN GAP FILLERS	LOCATION CODE	SHORT GAP	NORMAL TO DOOR	CHIN PANEL
Tile 1: _____	-	-	-	-	-	-
Tile 2: _____	-	-	-	-	-	-
Tile 3: _____	-	-	-	-	-	-
Tile 4: _____	-	-	-	-	-	-
Tile 5: _____	-	-	-	-	-	-
Tile 6: _____	-	-	-	-	-	-
Tile 7: _____	-	-	-	-	-	-
Tile 8: _____	-	-	-	-	-	-

On this screen you tell the program about the tile being evaluated.

TILE TO TILE INTERSECTIONS: Input one of the surrounding tile part numbers. If the array number is the same as the tile you are evaluating then just enter the three digit tile number (for example: the tile being evaluated is 191002-123, to enter the tile 191002-124 just enter 124).

CAVITY DWG NUMBER: This will be initiated only when the tile is an instrumentation tile. A cavity drawing number is required for the evaluation.

DESIGN GAP FILLER: Then the program needs to know about the status of the gap. This is input in the Design Gap Fillers column.

A - Ames Fill
S - Partial (and Single) Ames
P - Pillow Type Gap Filler
I - Installed
C - Captive Gap Filler
T - Thermal Barrier
E - Empty

These are the design requirements, not what is actually in the gap.
For clarification:

E - Empty: No gap filler installed or needed by design. Ames rework in place (not be design). Effective net gap measurement needed.
A - Ames Filler: Ames Filler required by design.
S - Partial Filler: Partial (or single) Ames Filler required by design.
P - Pillow Filler: Pillow Filler by design (but not installed).
I - Installed: Pillow Filler by design (already installed).
C - Captive Filler: Captive Filler by design (installed or not).
T - Thermal Barrier: Thermal barrier by design (must be installed).

LOCATION CODE: Certain tiles that are in the Special Figures of MLO601-0001 have a "location code." This must also be input for the program to generate the P-310 correctly. You'll have to reference the MLO601-0001 for this information.

SHORT GAP: Some of the Special Figures also need to know if the gap is a "short" gap or a "long" gap. It is answered with Y for a short gap or N for a long one.

NORMAL TO DOOR: Normal means perpendicular. The program needs to know if the gap being evaluated is normal to any gaps at the edge of a door (see figure 1 of MLO601-001). The gaps normal to the door will not have a thermal barrier in them.

CHIN PANEL: There is an additional column that is displayed only when needed. It is concerned with the Special Figures, but it varies in use depending on the figure. The example here asks if this is a **CHIN PANEL** tile. Other headings are: Trailing edge, Outboard door gap, Inboard door gap, Aft of X = 1039, Internal tile, Upper surface, and 307 nominal gap. Please enter a Y for yes or a N for no to complete this column.

MID POINT DATA ENTRY FOR STEP AND GAP

TILE TO TILE	STEP	GAP	RECESSION
191002-123/191002-124	___	___	_____
191002-123/191002-125	___	___	_____
191002-123/191002-126	___	___	_____

The step, gap and recession/protrusion are input here.

TILE TO TILE: The data displayed here is formed from the tile to tile part numbers you entered in the Mid Point initialization (the second screen you filled in).

STEP: The step measurement in mils.

GAP: The gap measurement in mils. Remember that these measurements are entered in the same order that you input the tile to tile intersections.

RECESSION: The recession/protrusion is entered only for thermal barriers.

The step, gap, and recession/protrusion measurements are all entered in mils. For example: to enter 35 mils you would just enter 35; you should not enter 0.035.

CORNER INITIALIZATION

CORNER 1	CORNER 2	CORNER 3
NUMBER OF TILES: _	NUMBER OF TILES: _	NUMBER OF TILES: _
TILE 2: _____	TILE 2: _____	TILE 2: _____
TILE 3: _____	TILE 3: _____	TILE 3: _____
TILE 4: _____	TILE 4: _____	TILE 4: _____

CORNER 4	CORNER 5	CORNER 6
NUMBER OF TILES: _	NUMBER OF TILES: _	NUMBER OF TILES: _
TILE 2: _____	TILE 2: _____	TILE 2: _____
TILE 3: _____	TILE 3: _____	TILE 3: _____
TILE 4: _____	TILE 4: _____	TILE 4: _____

CORNER 7	CORNER 8
NUMBER OF TILES: _	NUMBER OF TILES: _
TILE 2: _____	TILE 2: _____
TILE 3: _____	TILE 3: _____
TILE 4: _____	TILE 4: _____

If you have requested a Corner Step evaluation, this screen will appear. You will input the tile to tile part numbers of the corners to be evaluated. You do not have to (in fact it is incorrect to) list the tile being evaluated. It is already assumed present.

NUMBER OF TILES: Just tell how many tiles are at that corner (3 or 4 are the only valid responses). The program will force you to enter a 3 or a 4.

TILE #: Then fill in the adjacent tile part number (if the array number is the same as the tile you are evaluating then just enter the three digit tile number.

CORNER DATA ENTRY FOR STEP AND GAP

CORNER NUMBER: 1 STEP TOOL TYPE (L/C/T/S):__

TILE TO TILE

1) - 191002-123
2) - 191002-124
3) - 191002-125

	(1-2)	(2-3)	(1-3)
STEP:	____	____	____
GAP:	____	____	____
STATUS:	-	-	-
RECESSION:	____	____	____

The step, gap, gap filler and recession/protrusion are input here.

STEP TOOL TYPE (L/C/T/S): The computer tries to choose the correct tool type to use. If you are using a corner step tool this will be chosen for 3 corner tiles. Trammel tools are chosen for 4 corner tiles. If a different tool type was used you will need to tell the computer what kind of tool. Cancel back (use the numeric keypad 0 key) and your choices are L for Laser, C for Corner Step, T for Trammel, or S for Shims. Just enter the first letter from the one used and the program will understand the step reading you input.

STEP: Enter the Step measurements for the corner. You don't have to calculate the step when a Corner Step tool was used. because the program is smart enough to do that for you.

GAP, GAP STATUS, RECESSION: Complete the corner by entering the corresponding gap, gap status, and where appropriate the recession. The gap status in one of the following:

E - Empty	A - Ames Gap Filler
I - Installed Pillow Gap Filler	P - Pillow Gap Filler
C - Captive Gap Filler	T - Thermal Barrier

Where (I)nstalled is for non-design pillow gap filler and (P)illow is for design pillow gap filler on the wing training edge.

Finishing up:

Now you have input all the necessary information. The program will take a little time (about 15 seconds) to finish evaluating and printing its version of a P-310. All that is left to do is get the printout and check it for correctness and completeness. You must document any out of tolerance conditions and see that they are handled correctly. Attach the data map and the computers results to the TPS and proceed to the next evaluation.

To exit the program type **EXIT** at the **WAD NO.** prompt.

Appendix III

Step and Gap Case Studies

Trainer's Recognition Test Matrix

TECHNICIAN _____ DATE _____

	OK	MISRECOGNITION
Enter Repeat Message		
Enter Help		
Enter Cancel		
Enter Pillow		
Enter Carrier Panel		
Enter Partial AEMS		
Enter Piilow Gap Filler		
Enter Installed		
Enter Number Sierra Echo 2 3 4 5		
Enter Number 0 1 2 3 4 5 6 7 8 9		
Enter Laser		
Enter Yes		
Enter No		
Enter Number 9 8 7 6 5 4 3 2 1		
Enter Aft-5-07-148		
Enter Vert-2-08-567		
Enter Aft		
Enter Number Zulu Sierra 2314		
Enter Captive Gap Filler		
Enter Vertical 9		
Enter Hello Paul		
Enter Aims		
Enter Right Pod 6		
Enter Less		
Enter Number Mid Dash 5591		
Enter Frizzy		
Enter Forward 9335-148		
Enter Number Victor Charlie 525		
Enter Gulf 3322		
Enter Thermal Barrier		
Enter Mid Minus 2 1 1 9		
Enter Shims		
Enter Fib		
Enter Payload Bay Door-06-22-345		
Enter Right Wing 5		
Enter Number Papa Keelo 65-22		
Enter Number Leema Yankee-16-123		
Enter Shims		
Enter Hello Betty		

...RK IN ACCORDANCE WITH ...0601-0001 PROCESS 310 ...ROCEDURE A QE 054 SPC SEP 2 88	MID POINTS FINAL STEP AND GAP	MAD NO. RMMG-3-07-140 PART NO. V070-191002-231 DATE 9/19/88 TIME 16:15	
		TECH	CONTRA QA	NASA QA
TILE NO. V070-191002-231 OCN LW3060		.....	.....	.....
DATA ENTERED BY: TAMIM HAMID		.....	.....	.....
( ) MID POINT STEP AND GAP (X) CORNER AND MID POINT STEP AND GAP		.....	.....	.....
STEP TOOL TYPE / Z NUMBER / CALIBRATION DUE CRAMMEL ( ) LASER (X) ZA0467 12-12-88 SHIMS ( ) N/A N/A		.....	.....	.....
ALLOWABLE STEP AND GAP PER ML0601-0001 PAGE: 35		.....	.....	.....

JG / JC	EMI / COD	UNFILLED GAP STEP FWD	UNFILLED GAP STEP AFT	UNFILLED GAP GAP	FILLED GAP STEP FWD	FILLED GAP STEP AFT	FILLED GAP GAP	REMARKS
	2/L	030 030	050 057	019-065 019-045	030 057	040 -	066-085 019-045	

TILE TO TILE	LCODE	GAP STATUS	STEP	GAP	T/R(+,-)
191002-231/191002-232	/	AMES FILL	+005	035	
191002-231/191002-230	/	CAPTIVE GAP FILLER	+025	020	
191002-231/191002-175	/	PILLOW GAP FILLER	+010	015	

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VERIFY CSR-118		0
VERIFY DATA	I	0

PAGE 2 OF 2 — MID POINTS FINAL STEP AND GAP — BWNG-3-07-14M

TILE TO TILE	ACTUAL SIDE STEP	ACTUAL SIDE GAP	T/B PROT (+) REC (-)	LONG OR SHORT GAPS L	LONG OR SHORT GAPS S	MINIMUM GAPS GAP AVG. CALCULATION	INSTALL TO DWGS TECH OPS T	INSTALL TO DWGS PIL-LOW	INSTALL TO DWGS AMES	REWORK TO SPEC AMES FILL	REWORK TO SPEC PAD TYPE G/E	REWORK TO SPEC AMES TO NOM.	U N A C P I	A C C E P T
191002-231 / 191002-232	+005	035							X					.... / ....
191002-231 / 191002-230	+025	020												
191002-231 / 191002-175	+010	015												
0														
1														
2														

VERIFY CSR 344 REQD FOR MANUAL EVALUATIONS ONLY: R_____ NR_____	EVALUATION COMPLETE	T	Q
EAB PAD TYPE G/E/PILLOW G/E INSILN · PROCESS 601 NR ____	INSTL OF AMES G/F INSILN [ ] PROCESS 602 NR ____	T	.....
CONTINUATION PAGE WRITTEN AGAINST O/T STEP, GAP OR T/B RECESSION PROTRUSION FOR 'NEWLY INSTALLED' TILE TO ADJACENT TILES DR/PR NUMBER _____ NR _____		.....	Q
INSPECTION VERIFY THAT INSTALLATION COMPLIES WITH SPECIFICATION REQUIREMENTS		.....	Q (A)
STEP AND GAP COMPLETE		.....	Q

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* Adjacent part number criteria used. (A) NASA INSPECTION REQUIRED FOR MANUAL EVALUATION ONLY.

RK IN ACCORDANCE WITH 0601-9024, PROCESS 310, OCEDURE B. QE SEP 22 8:54 SPC	CORNER STEP AND GAP (REF. ML0601-0001, FIGURE 17)	WAD NO. RWUG-3-07-148
P[illegible]Y R-118 Q: _____		PART NO. V070-191002-231
		DATE 9/19/88 TIME 16:15

	TECH	CONTRA INSP.	NASA INSP.
ILE NO. V070-191002-231 OCN LW3060	.....	.....	.....
ATA ENTERED BY: TAMIM HAMID	.....	.....	.....
ECORD STEP TOOL TYPE ( ) CORNER STEP ( ) TRAMMEL ( ) SHIMS	.....	.....	.....
	.....	.....	.....
ECORD Z NO. N/A	.....	.....	.....
AL. DUE DATE N/A	.....	.....	.....
ECORD AREA IN REGION 'A' (REF:ML0601-0001 FIG.32) 1.[X] 2.[ ] 3.[ ] 4.[ ] 5.[ ] 6.[ ]	.....	.....	.....

ILE	STEP	STEP	STEP	STEP	STEP	STEP		GAP	GAP	GAP	GAP
191002-232	(1-2) +012	(2-3) +015	(3-1) +022					(1-2) 018	(2-3) 030	(3-1) 032	
191002-230							G/E STATUS-> REC/PROT->	E	A	I +012	
191002-235	(1-2) +017	(2-3) +023	(3-1) +033					(1-2) 011	(2-3) 016	(3-1) 048	
191002-236							G/E STATUS-> REC/PROT->	E	A	E	
							G/E STATUS-> REC/PROT->				
							G/E STATUS-> REC/PROT->				
							G/E STATUS-> REC/PROT->				
							G/E STATUS-> REC/PROT->				
							G/E STATUS-> REC/PROT->				
							G/E STATUS-> REC/PROT->				

PAGE 1 OF 2 VERIFY DATA: I: _____ Q: _____

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PAGE 2 OF 2 QE 054 SPC SEP 22 89 UNACCEPTABLE CORNER STEP AND GAP EVALUATION SHEET RWNG-3-07-140

ITEM	CORNER INTERSECTION DRAWING - TILE	LARGEST CORNER STEP	TILE-TILE CORNER GAP	PILLOW, PAD TYPE, T/B REC(-) PRO(+)	ENGINEERING EVALUATION LOCAL REQ	AREA ALLOW	NORM REQ	REMARKS	ENG. INIT.
1									
2									
3									
4									
5									
6									
7									
8									

PR/CONTINUATION PAGE INITIATED FOR UNACCEPTABLE CONDITION(S) 0 .....
RECORD DR/PR _____ PG. _____ N.R. _____ .....

STEP AND GAP COMPLETE 0 .....
.....

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[illegible] PART_NO:191002-231
1002-231 / 191002-232
Criteria is FORMAT 2.
Step is forward facing.
Step meets unfilled criteria.
Gap meets unfilled criteria. No rework.
Makes Fill/Drawing.

1002-231 / 191002-230
Criteria is FORMAT 2.
Step is forward facing.
Step meets unfilled criteria.
Gap meets unfilled criteria. No rework.
INVALID CRITERIA FOR DESIGN CAPTIVE GAP FILLER!
Criteria may not be checked.

1002-231 / 191002-175
Criteria is FORMAT 2.
Step is forward facing.
Step meets unfilled criteria.
Gap failed unfilled criteria.
Gap failed filled criteria.
Gap failed minimum gap criteria. Try gap averaging.
INVALID CRITERIA FOR DESIGN PILLOW GAP FILLER!
Criteria may not be checked.

OE 054 SPC SEP 22 --

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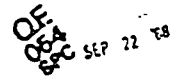
[illegible] Req Results for [illegible]
Eng MR Area 1

1002-231 191002-232 191002-230
MAX STEP: 022
GAP USED: 018 GAP STATUS: Empty
Req: 022
MR Area 073
NORM Req: 033



1002-231 191002-235 191002-236
MAX STEP: 033
GAP USED: 048 GAP STATUS: Empty
Req: 033
MR Area 073
NORM Req: 050

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WORK IN ACCORDANCE WITH
MLO601-0001 PROCESS 310
PROCEDURE A

CE 054 SPC 53 2-28

MID POINTS
FINAL STEP AND GAP

WAD NO.	VERT-2-08-298
PART NO.	V070-193011-330
DATE	9/19/80 TIME 14:51

TECH	CONTRA QA	NASA QA
.....	.....	.....

TILE NO. V070-193011-330 OCN XR6913

DATA ENTERED BY: TAMIM HAMID

( ) MID POINT STEP AND GAP
(X) CORNER AND MID POINT STEP AND GAP

STEP TOOL TYPE		Z NUMBER	CALIBRATION DUE
TRAMMEL	(X)	ZA0467	12-12-80
LASER	( )		
SHIMS	(X)	N/A	N/A

ALLOWABLE STEP AND GAP PER MLO601-0001 PAGE: 53

JG / TC	EMT COD	UNFILLED GAP STEP FWD	UNFILLED GAP STEP AFT	UNFILLED GAP GAP	FILLED GAP STEP FWD	FILLED GAP STEP AFT	FILLED GAP GAP	REMARKS
	3/L	030	050	016-035	030 050	050 -	036-150 016-150	
	7/L	030	050	287-327	050	050	130-327	307 NOM. GAP

TILE TO TILE	LCODE	GAP STATUS	STEP	GAP	T/E(+,-)
193011-330/193011-331	1/1	AMES FILL	+014	028	
193011-330/193011-332	1/4	PILLOW GAP FILLER 307 NOMINAL GAP	+023	005	
193011-330/191104-125	1/0 -	THERMAL BARRIER INBOARD DOOR GAP	+017	009	-010

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VERIFY DATA T O

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MID POINTS FINAL STEP AND GAP

VERI-3-08-309

TILE TO TILE	ACTUAL SIDE STEP	ACTUAL SIDE GAP	T/B PROT (+) REC (-)	LONG OR SHORT GAPS L	LONG OR SHORT GAPS S	GAP AVG. CALCULATION	MINIMUM GAPS TECH OPS T	INSTALL TO DWGS PILLOW	AMES	REWORK TO SPEC AMES FILL	PAD TYPE G/E	AMES TO NOM.	U N A C P T	A C C E P T
193011-330	+014	028							X					....
193011-331														....
193011-330	+023	005						N/P					X	....
* 193011-332														....
193011-330	+017	009	-010											
191104-125														
0														
1														
2														

VERIFY CSR 344 REQD FOR MANUAL EVALUATIONS ONLY: Q_____ NR_____	EVALUATION COMPLETE	T	Q	....
PAD PAD TYPE G/E/PILLOW G/E INSITN PROCESS 601 NR ____	INSTL OF AMES G/E INSITN [] PROCESS 602 NR ____	T	....	....
CONTINUATION PAGE WRITTEN AGAINST O/I STEP, GAP OR T/B RECESSION PROTRUSION FOR 'NEWLY INSTALLED' TILE TO ADJACENT TILES O/R/PR NUMBER _____ NR _____		....	Q	....
INSPECTION VERIFY THAT INSTALLATION COMPLIES WITH SPECIFICATION REQUIREMENTS		....	Q	N (*)
STEP AND GAP COMPLETE		....	Q	....

Adjacent part number criteria used. (*) NASA INSPECTION REQUIRED FOR MANUAL EVALUATION ONLY.

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ORK IN ACCORDANCE WITH
L0601-9024, PROCESS 310,
ROCEDURE 8.

ERIEF

SR-118 Q: _____

QE 054 SRC. SEP 22 '88

CORNER

STEP AND GAP
(REF. ML0601-0001,
FIGURE 17)

	TECH	CONTRA INSP.	NASA INSP.
WAD NO.	VERT-2-08-298		
PART NO.	V070-193011-330		
DATE 9/19/88 TIME 14:52			

TILE NO. V070-193011-330 OCN XR6913

DATA ENTERED BY: TAMIM HAMID

RECORD STEP TOOL TYPE
( ) CORNER STEP (X) TRAMMEL ( ) SHIMS

RECORD Z NO. ZA0467 N/A
CAL. DUE DATE 12-12-88 N/A

RECORD AREA IN REGION 'A' (REF:ML0601-0001 FIG.32)
1.[ ] 2.[ ] 3.[X] 4.[ ] 5.[ ] 6.[ ]

TILE	STEP	STEP	STEP	STEP	STEP	STEP	GAP	GAP	GAP	GAP
193011-334	(1-2) +015	(2-3) +017	(3-1) +020				(1-2) 007	(2-3) 016	(3-1) 021	
193011-335					G/F STATUS-> REC/PROT->		E	E	A	
193011-341	(1-2) +022	(2-3) +018	(3-1) +013				(1-2) 000	(2-3) 027	(3-1) 033	
193011-336					G/F STATUS-> REC/PROT->		A	I +013	E	
					G/F STATUS-> REC/PROT->					
					G/F STATUS-> REC/PROT->					
					G/F STATUS-> REC/PROT->					
					G/F STATUS-> REC/PROT->					
					G/F STATUS-> REC/PROT->					

PAGE 1 OF 2 VERIFY DATA: T: _____ Q: _____

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AGE 2 OF 2 QE 054 SPC SEP 22 '89 UNACCEPTABLE CORNER STEP AND GAP EVALUATION SHEET VERT-2-08-290

	CORNER INTERSECTION DRAWING - TILE	LARGEST CORNER STEP	TILE-TILE CORNER GAP	PILLOW, PAD TYPE, I/B REC(-) PRO(+)	ENGINEERING EVALUATION LOCAL KEQ	AREA ALLOW	NOBR KEQ	REMARKS	ENG. INIT.
2									
3									
4									
5									
6									
7									
8									

PR/CONTINUATION PAGE INITIATED FOR UNACCEPTABLE CONDITION(S) 0 .....
RECORD DR/PR _____ PG. _____ N.R. _____ .....

AND GAP COMPLETE 0 .....
.....

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B NO:VERT-2-09-20W PART_NO:193011-330
3011-330 / 193011-331
riteria is FORMAT 6 (or special case format).
Location code is ->1
See Figure 10.
Criteria is FORMAT 3
Step is forward facing.
Step meets unfilled criteria.
Gap meets unfilled criteria. No rework.
Ames Fill/Drawing.

3011-330 / 193011-332
riteria is FORMAT 6 (or special case format).
Location code is ->1
See Figure 10.
Criteria is FORMAT 3
Step is forward facing.
Step meets unfilled criteria.
Gap failed unfilled criteria.
Gap failed filled criteria (top line).
Gap failed minimum gap criteria. Try gap averaging.
INVALID CRITERIA FOR DESIGN PILLOW GAP FILLER!
Criteria may not be checked.
93011-330 / 193011-332A
Criteria is FORMAT 6 (or special case format).
Location code is ->4
See Figure 10.
Criteria is FORMAT 7.
Step is forward facing.
Step meets filled criteria.
Gap failed filled criteria. Unacceptable.

1-330 / 191104-125
riteria is FORMAT 6 (or special case format).
Location code is ->1
Gap is a thermal barrier gap.
Tile not found in FORMAT 6 database ->193011-330, Location code->1T
CRITERIA NOT CHECKED!
93011-330 / 191104-125A
Criteria is FORMAT 6 (or special case format).
Location code is ->0
See figure 9 & 27.
Criteria is FORMAT 7.
Step is forward facing.
Step meets filled criteria.
Gap failed filled criteria. Unacceptable.
Recession meets criteria.

QE 054 SRC SEP 22 '88

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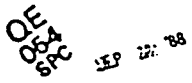
Ogest Req results for 193011-330
ing MR Area 3

3011-330 193011-334 193011-335
MAX STEP: 020
G USED: 007 GAP STATUS: Empty
[redacted]: 020
MR Area 100
NORM Req: 022



3011-330 193011-341 193011-338
MAX STEP: 022
GAP USED: 000 GAP STATUS: Ames Gap Filler
Req: 022
MR Area 100
NORM Req: 024

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CASE 3 (VOICE)

SEP 72 S OE 054 SPC

DI[illegible]IN ACCORDANCE WITH [illegible]01-0001 PROCESS 310 PROCEDURE A	MID POINTS FINAL STEP AND GAP	WAD NO. PLBD-4-03-436 PART NO. V070-191101-268 DATE 9/19/88 TIME 15:16		
		TECH	CONTRA QA	NASA QA
TILE NO. V070-191101-268	OCN S80200	.....	.....	.....
DATA ENTERED BY: TAMIM HAMID		.....	.....	.....
( ) MID POINT STEP AND GAP (X) CORNER AND MID POINT STEP AND GAP		.....	.....	.....
STEP TOOL TYPE TRAMMEL ( ) LASER ( ) SHIMS (X)	Z NUMBER N/A	CALIBRATION DUE N/A	.....	.....
ALLOWABLE STEP AND GAP PER ML0601-0001 PAGE: 70			.....	.....

JG / JC	FMT / COD	UNFILLED GAP STEP FWD	UNFILLED GAP STEP AFT	UNFILLED GAP GAP	FILLED GAP STEP FWD	FILLED GAP STEP AFT	FILLED GAP GAP	REMARKS
	7/L	000	000	000-000	030	030	270-470	OUTBOARD DOOR GAP
	/L	030	030	025-065	030	030	025-085	NORMAL TO DOOR

TILE TO TILE	LCODE	GAP STATUS	STEP	GAP	T/B(+,-)
191101-268/191101-269	0/0	THERMAL BARRIER OUTBOARD DOOR GAP	+033	031	+010
191101-268/191101-270	0/0	THERMAL BARRIER OUTBOARD DOOR GAP	+024	017	+013
191101-268/191101-271	0/0	AMES FILL NORMAL TO DOOR	+016	015	

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VERIFY DATA | T | V

QE 0554 84C SEP 22 '80 MID POINTS FINAL STEP AND GAP - PLDD-4-03-426

I T E M	TILE TO TILE	ACTUAL SIDE STEP	ACTUAL SIDE GAP	T/B PROT (+) REC (-)	LONG OR SHORT GAPS L	LONG OR SHORT GAPS S	MINIMUM GAPS GAP AVG. CALCULATION	INSTALL TO DWGS TECH OPS T	INSTALL TO DWGS FIL-LOW	AMES FILL	REWORK TO SPEC AMES FILL	REWORK TO SPEC PAD TYPE G/E	REWORK TO SPEC AMES TO NOM.	O R G P T	A C C E P T
1	191101-268 191101-269	+033	021	+010										X	
2	191101-268 191101-270	+034	017	+012										X	
3	191101-268 191101-271	+016	015												
4															
5															
6															
7															
8															
9															
10															
11															
12															

VERIFY CSR 344 REQD FOR MANUAL EVALUATIONS ONLY: Q_____ NR_____	EVALUATION COMPLETE	T	Q	.....
				.....
EAB PAD TYPE G/E/PILLOW G/E INSTLN PROCESS 601 NR ____	INSTL OF AMES G/E INSTLN [ ] PROCESS 602 NR ____	T	.....	.....
			.....	.....
TINUATION PAGE WRITTEN AGAINST O/T STEP, GAP OR T/B RECESSION		.....	Q	.....
TRUSION FOR 'NEWLY INSTALLED' TILE TO ADJACENT TILES		.....		.....
DR/PR NUMBER _____ NR _____		.....		.....
INSPECTION VERIFY THAT INSTALLATION COMPLIES WITH SPECIFICATION REQUIREMENTS		.....	Q	N (*)
		.....		

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K IN ACCORDANCE WITH 601-9024, PROCESS 310, PROCEDURE D.	CORNER	WAD NO. PLBD-4-00-426
		PART NO. V070-191101-268
VERIFY SEP 22 '88 OE 054 SPC CSR-116 Q: _____	STEP AND GAP (REF. MLO601-0001, FIGURE 17)	DATE 9/19/88 TIME 15:16

	TECH	CONTRA INSP.	NASA INSP.
TILE NO. V070-191101-268 OCN S80200	.....	.....	.....
DATA ENTERED BY: TAMIM HAMID	.....	.....	.....
RECORD STEP TOOL TYPE (X) CORNER STEP ( ) TRAMMEL ( ) SHIMS	.....	.....	.....
RECORD Z NO. 282971 N/A	.....	.....	.....
CAL. DUE DATE 11-12-88 N/A	.....	.....	.....
RECORD AREA IN REGION 'A' (REF:MLO601-0001 FIG.32) 1.[ ] 2.[ ] 3.[ ] 4.[ ] 5.[X] 6.[ ]	.....	.....	.....

TILE	STEP	STEP	STEP	STEP	STEP	STEP		GAP	GAP	GAP	GAP
191101-278	(C-S) +012	(C-S) +008	(C-S) +005					(1-2) 017	(2-3) 014	(3-1) 016	
191101-279							G/E STATUS-> REC/PROT->	E	E	E	
191101-280	(C-S) +025	(C-S) +030	(C-S) +015					(1-2) 018	(2-3) 013	(3-1) 012	
191101-281							G/E STATUS-> REC/PROT->	E	E	E	
							G/E STATUS-> REC/PROT->				
							G/E STATUS-> REC/PROT->				
							G/E STATUS-> REC/PROT->				
							G/E STATUS-> REC/PROT->				
							G/E STATUS-> REC/PROT->				

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QE 054 SPC SEP 22 '88

UNACCEPTABLE CORNER STEP AND GAP EVALUATION SHEET

PLDD-4-03-436

ITEM NO	CORNER INTERSECTION DRAWING - TILE	LARGEST CORNER STEP	TILE-TILE CORNER GAP	PILLOW, PAD TYPE, I/B REC(-) PRO(+)	ENGINEERING EVALUATION TOTAL REQ	AREA ALLOW	NORM REQ	REMARKS	ENG. INIT.
1									
2									
3									
5									
6									
7									

PR/CONTINUATION PAGE INITIATED FOR UNACCEPTABLE CONDITION(S) 0 .....
RECORD DR/PE _____ PG. _____ N.R. _____ .....

STEP AND GAP COMPLETE 0 .....

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(NO:PLBD-4-03-436 PART_NO:191101-268
91101-268 / 191101-269
Criteria is FORMAT 6 (or special case format).
 Location code is ->0
  See figure 9 & 27.
   Criteria is FORMAT 7.
    Step is forward facing.
     Step failed filled criteria.
        gap also failed filled gap criteria. Unacceptable.
       Protrusion is also too big!

91101-268 / 191101-270
Criteria is FORMAT 6 (or special case format).
 Location code is ->0
  See figure 9 & 27.
   Criteria is FORMAT 7.
    Step is forward facing.
     Step meets filled criteria.
      Gap failed filled criteria. Unacceptable.
       Protrusion is also too big!

91101-268 / 191101-271
Criteria is FORMAT 6 (or special case format).
 Location code is ->0
  Gap is normal to the door edge.
   See figure 9 & 27.
    Criteria is FORMAT 7.
     Step is forward facing.
      Step meets filled criteria.
       Gap failed filled criteria. Unacceptable.
        INVALID CRITERIA FOR GAP WITH NO
        DESIGN GAP FILLERS!
         Criteria may not be checked.

SEP 22 '80 DOE/JSC

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Adjacent part number criteria used. (A) NASA INSPECTION REQUIRED FOR MANUAL EVALUATION ONLY.

Request Req results for 191101-260
in MR Area 5

1101-268 191101-278 191101-279
MAX STEP: 007
GAP USED: 017 GAP STATUS: Empty
Req: 007
MR Area 140
NORM Req: 006

1101-268 191101-280 191101-281
MAX STEP: 010
GAP USED: 018 GAP STATUS: Empty
Req: 010
MR Area 140
NORM Req: 008

SEP 22 '88

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ORK IN ACCORDANCE WITH
L0601-0001 PROCESS 310
ROCEDURE A

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054
SPC
SEP 22 '89

MID POINTS

FINAL STEP AND GAP

WOD NO. RWNG-5-00-X59

PART NO. V070-391096-123

DATE 9/19/88 TIME 15:50

	TECH	CONTRA QA	NASA QA
TILE NO. V070-391096-123 OCN CE6789	....	....	....
DATA ENTERED BY: TAMIM HAMID	....	....	....
( ) MID POINT STEP AND GAP (X) CORNER AND MID POINT STEP AND GAP	....	....	....
STEP TOOL TYPE — Z NUMBER — CALIBRATION DUE TRAMMEL (X) — ZS3214 — 10-23-88 LASER ( ) SHIMS (X) — N/A — N/A	....	....	....
ALLOWABLE STEP AND GAP PER ML0601-0001 PAGE: 36	....	....	....

WG OC	FMT COD	UNFILLED GAP STEP EWD	UNFILLED GAP STEP AFT	UNFILLED GAP GAP	FILLED GAP STEP EWD	FILLED GAP STEP AFT	FILLED GAP GAP	REMARKS
	1/U	080	100	016-075	100	100	076-150	

TILE TO TILE	LCODE	GAP STATUS	STEP	GAP	I/B(+,-)
391096-123/391096-124 (391047)	/	AMES FILL	+028	028	
391096-123/190002-145 391047)	/	THERMAL BARRIER AFT OF X = 1039	+023	011	+010
391096-123/199702-155 391047)	/		+031	009	
391096-123/391016-165 391047)	/3	CAPTIVE GAP FILLER SHORT GAP	+025	015	
391096-123/395016-175 391047)	/	TRAILING EDGE	+010	012	

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OE 054 SEP 22 '88

MID POINTS FINAL STEP AND GAP

EWNG-5-00-789

LE D TILE	ACTUAL SIDE STEP	ACTUAL SIDE GAP	T/B PROT (+) REC (-)	LONG OR SHORT GAPS L	SHORT GAPS S	MINIMUM GAPS GAP AVG. CALCULATION	INSTALL TO DWGS TECH OPS T	INSTALL TO DWGS PIL-LOW	INSTALL TO DWGS AMES	REWORK TO SPEC AMES FILL	REWORK TO SPEC PAD TYPE G/E	REWORK TO SPEC AMES TO NOM.	U N A C P T	A C C E P T
391096-123	+028	029							X					....
391096-124														....
391096-123	+023	011	+010											
190002-145														
391096-123	+031	009												
199702-155														
391096-123	+025	015			X									
391016-165														
391096-123	+010	012				X								
395016-175														

VERIFY CSR 344 REQD FOR MANUAL EVALUATIONS ONLY: Q_____ NR_____ | EVALUATION COMPLETE | T | Q | ..... | ..... |

FAB PAD TYPE G/E/PILLOW G/E INSTLN PROCESS 601 NR ____ | INSTL OF AMES G/E INSTLN TO PROCESS 602 NR ____ | T | ..... | ..... | ..... | ..... |

CONTINUATION PAGE WRITTEN AGAINST O/I STEP, GAP OR T/B RECESSION PROTRUSION FOR 'NEWLY INSTALLED' TILE TO ADJACENT TILES DR/PR NUMBER _____ NR _____ | ..... | Q | ..... | ..... | ..... | ..... |

INSPECTION VERIFY THAT INSTALLATION COMPLIES WITH SPECIFICATION REQUIREMENTS | ..... | Q | N (A) | ..... | ..... |

STEP AND GAP COMPLETE | ..... | Q | ..... | ..... | ..... |

Adjacent part number criteria used. (A) NASA INSPECTION REQUIRED FOR MANUAL EVALUATION ONLY.

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WORK IN ACCORDANCE WITH
MLO601-9024, PROCESS 310,
PROCEDURE B.

J[illegible]IEY

[illegible]SR-110 Q: _____

SEP 72 89 QE 054 SPC

CORNER

STEP AND GAP
(REF. MLO601-0001,
FIGURE 17)

WAD NO. AWNG-5-00-789

PART NO. V070-391096-123

DATE 9/19/88 TIME 15:50

	TECH	CONFIG INSP.	NASA INSP.
TILE NO. V070-391096-123 OCN CC6789	.....	.....	.....
DATA ENTERED BY: TAMIM HAMID	.....	.....	.....
RECORD STEP TOOL TYPE (X) CORNER STEP ( ) TRAMMEL ( ) SHIMS	.....	.....	.....
RECORD Z NO. ZH8855 N/A	.....	.....	.....
CAL. DUE DATE 12-23-88 N/A	.....	.....	.....
RECORD AREA IN REGION "A" (REF:MLO601-0001 FIG.32) 1.[ ] 2.[ ] 3.[ ] 4.[ ] 5.[ ] 6.[ ]	.....	.....	.....

TILE	STEP	STEP	STEP	STEP	STEP	STEP	GAP	GAP	GAP	GAP
2 391096-334	(C-S) +015	(C-S) +017	(C-S) +020				(1-2) 007	(2-3) 016	(3-1) 021	
3 391096-335										
4						G/E STATUS-> REC/PROT->	E	E	A	
2 391096-341	(C-S) +022	(C-S) +018	(C-S) +013				(1-2) 000	(2-3) 027	(3-1) 033	
3 391096-338										
4						G/E STATUS-> REC/PROT->	A	T +013	E	
2										
3										
4						G/E STATUS-> REC/PROT->				
2										
3										
4						G/E STATUS-> REC/PROT->				
2										
3										
4						G/E STATUS-> REC/PROT->				
2										
3										
4						G/E STATUS-> REC/PROT->				
2										
3										
4						G/E STATUS-> REC/PROT->				

PAGE 1 OF 2 VERIFY DATA: T: _____ Q: _____

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OE 054 SPEC SEP 22 '88

UNACCEPTABLE CORNER STEP AND GAP EVALUATION SHEET

RWNG-5-90-789

ITEM NO.	CORNER INTERSECTION DRAWING - TILE	LARGEST CORNER STEP	TILE-TILE CORNER GAP	PILLOW, PAD TYPE, T/B REC(-) PRO(+)	ENGINEERING EVALUATION LOCAL REQ	AREA ALLOW	NORM REQ	REMARKS	ENG. INIT.
3									
4									
5									
6									
7									
8									

PR/CONTINUATION PAGE INITIATED FOR UNACCEPTABLE CONDITION(S) 0 .....
RECORD DR/PR _____ PG. _____ N.R. _____ .....

AND GAP COMPLETE 0 .....
.....

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strumentation tile, using cavity drawing number =>391047
1096-123 / 395016-175
riteria is FORMAT 1.
Step is forward facing.
ep meets unfilled criteria.
ap failed unfilled criteria.
Step meets filled criteria.
Gap failed unfilled criteria.
Gap failed filled criteria.
Gap failed minimum gap criteria. Try gap averaging.
91096-123 / 395016-175*
FIGURE 14 (PG. 57) being processed as FORMAT 1.
Unfilled gap now 010-065, Filled gap 066-320.
Gap is now considered an upper surface gap.
Criteria is FORMAT 1.
Step is forward facing.
Step meets unfilled criteria.
Gap meets unfilled criteria. No rework.

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```
gest Req results for 391096-123
Error##A Invalid Area: 7
ng MR Area 1

096-123 391096-334 391096-335
A  STEP: 005
A  USED: 007  GAP STATUS: Empty
eq:      005
R Area   073
ORM Req: 008


096-123 391096-341 391096-338
AX STEP: 009
AP USED: 000  GAP STATUS: Ames Gap Filler
eq:      009
R Area   073
ORM Req: 014
```

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SEP 22 '88

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ORK IN ACCORDANCE WITH
L0601-0001 PROCESS 310
ROCEDURE A

MID POINTS
FINAL STEP AND GAP

WAD NO. FS1-3-07-311
PART NO. V070-391040-001
DATE 9/19/89 TIME 16:02

	TECH	CONTRA QA	NASA QA
TILE NO. V070-391040-001 OCN 456794			
DATA ENTERED BY: TAMIM HAMID			
(X) MID POINT STEP AND GAP ( ) CORNER AND MID POINT STEP AND GAP			
STEP TOOL TYPE Z NUMBER CALIBRATION DUE TRAMMEL (X) ZR7565 12-23-89 LASER ( ) SHIMS (X) N/A N/A			
ALLOWABLE STEP AND GAP PER MLO601-0001 PAGE: 44			

WG OC	EMT COD	UNFILLED GAP STEP FWD	UNFILLED GAP STEP AFT	UNFILLED GAP GAP	FILLED GAP STEP FWD	FILLED GAP STEP AFT	FILLED GAP GAP	REMARKS
	7/L	030	040	019-030	030	040	019-085	NORMAL TO DOOR
	7/L	000	000	000-000	030	040	105-135	THERMAL BARRIER

TILE TO TILE	LCODE	GAP STATUS	STEP	GAP	T/R(+,-)
391040-001/391017-002	3/1		+014	028	
391040-001/391017-003	3/1		+033	005	
391040-001/391040-004	3/3	CAPTIVE GAP FILLER NORMAL TO DOOR	+017	009	
391040-001/391040-005	0/0	THERMAL BARRIER	+014	028	-023
391040-001/CH/P	C/	CAPTIVE GAP FILLER	+033	005	

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MID POINTS FINAL STEP AND GAP

831-3-07-331

TILE NO TILE	ACTUAL SIDE STEP	ACTUAL SIDE GAP	T/B PROT (+) REC (-)	LONG OR SHORT GAPS L	LONG OR SHORT GAPS S	MINIMUM GAPS GAP AVG. CALCULATION	INSTALL TO DWGS TECH OPS T	INSTALL TO DWGS PIL-LOW	AMES	REWORK TO SPEC AMES FILL	REWORK TO SPEC PAD TYPE G/E	REWORK TO SPEC AMES TO NON.	O N A C F T	A C C E P T
391040-001 & 391017-003	+023	005											X	....
391040-001 391040-004	+017	009											X	....
391040-001 391040-005	+014	028	-023										X	....
391040-001 CH/P	+023	005												
0														
1														
2														

VERIFY CSR 344 REQD FOR MANUAL EVALUATIONS ONLY: O_____ NR_____	EVALUATION COMPLETE	I	O ....
TAB PAD TYPE G/E/PILLOW G/E INSILN PROCESS 601 NR ____	INSIL OF AMES G/E INSILN [] PROCESS 602 NR ____	I	....
CONTINUATION PAGE WRITTEN AGAINST O/T STEP, GAP OR T/B RECESSION PROTRUSION FOR 'NEWLY INSTALLED' TILE TO ADJACENT TILES DR/FR NUMBER _____ NR _____	....	.....	O ....
INSPECTION VERIFY THAT INSTALLATION COMPLIES WITH SPECIFICATION REQUIREMENTS	....	.....	O N (*)
STEP AND GAP COMPLETE	....	.....	O ....

Adjacent part number criteria used. (*) NASA INSPECTION REQUIRED FOR MANUAL EVALUATION ONLY.

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ing adjacent tile criteria, see figure 1.
91040-001 / 391017-002A
Criteria is FORMAT 6 (or special case format).
Location code is ->1
See Figure 1.
Criteria is FORMAT 3
Step is forward facing.
Step meets unfilled criteria.
Gap meets unfilled criteria. No rework.

ing adjacent tile criteria, see figure 1.
91040-001 / 391017-003A
Criteria is FORMAT 6 (or special case format).
Location code is ->1
See Figure 1.
Criteria is FORMAT 3
Step is forward facing.
Step meets unfilled criteria.
Gap failed unfilled criteria.
Gap failed filled criteria (top line).
Gap failed minimum gap criteria. Try gap averaging.

1040-001 / 391040-004
riteria is FORMAT 6 (or special case format).
Location code is ->3
Gap is normal to the door edge.
See Figure 1 & 26.
Criteria is FORMAT 7.
Step is forward facing.
Step meets filled criteria.
Gap failed filled criteria. Unacceptable.

1040-001 / 391040-005
riteria is FORMAT 6 (or special case format).
Location code is ->0
Gap is a thermal barrier gap.
See Figure 1 & 26.
Criteria is FORMAT 7.
Step is forward facing.
Step meets filled criteria.
Gap failed filled criteria. Unacceptable.
Recession meets criteria.

1040-001 / CH/P
riteria is FORMAT 6 (or special case format).
Location code is ->C
Tile not found in FORMAT 6 database ->391040-001, Location code->C!
CRITERIA NOT CHECKED!

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Appendix IV

Managerial / Supervisor's Training Aids

A. VDES Benefits and area of High Impact

B. Equipment use

APPENDIX IV

Managerial/Supervisor's Training Aids

A. VDES Benefits and area of High Impact.

The following are the contents of a set of slides or transparencies to be used to highlight the advantages of VDES over the manual system for P-310.

Slide 1.

Step and Gap processing
Time/Cost savings for Processing

Current	Time	Cost (approx.)
Processing per tile	2.5 hrs.	$250 (@ $100/hr.)
Processing per mission	125 hrs.	$12,500

VDES

Processing per tile	18 min.	$30
Processing per mission	15 hrs.	$1,500

Approximately $11,000 per mission. VDES will allow a throughput of 32 tiles/day per technician vs. 2 tiles per day per technician using manual system.

Slide 2.

Intangible Benefits

- Accurate data
  - Eliminates manual data transfer
  - Real-Time data evaluation
  - Up-to-date tile data
- Reduction in training time
- Faster data entry
- Reduction in skill requirement
- Ease of management
- Interface to Central Computer system

- Possible interaction with other "Hi-tech" communication facilities such as Bar Coding
- Possible redesign of the P-310 making use of the 'free-hand" environment

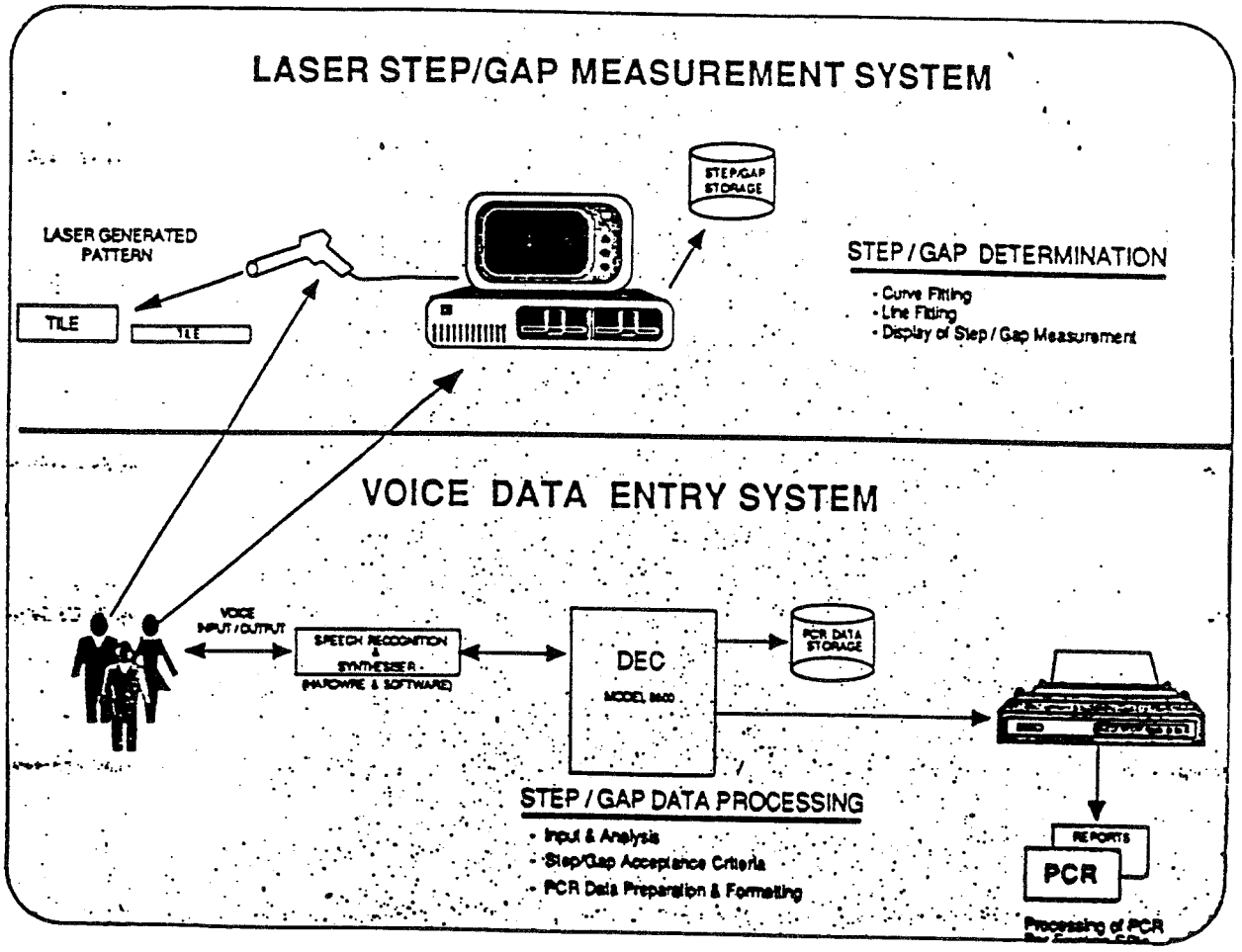
Slide 3

Characteristics of potential areas for VDES use

- Large amounts of data
- Stability of the user on the job
- Verification requirements
- Jobs which may require the use of the hand while communicating with a machine
  (Examples an all job requiring measurement).

B. VDES Equipment use

Slide 1. System Elements



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Technical Papers and Conference Presentations

Technical Papers / Conference Presentations :

- Cindy L. Mollakarimi , Tamim S. Hamid, (Lockheed), UCF project recognized, "Remote Voice Training: A case study on Space Shuttle Applications", AVIOS '89 Conference Proceedings and presentation, September 12-14, 1989, Los Angeles, CA.

- Yasser A. Hosni, John Scarboro, (UCF), Tamim Hamid (Lockheed); 12th Conference on Computers and Industrial Engineering, March 12-14, 1990, Orlando, Florida.

- Tim Barth, Yasser Hosni, and William Swart, "Improving Productivity of Space Shuttle Processing"; Proceedings IIE Aerospace and Defense Division 13th Annual Spring Conference, Orlando, Fl., Feb. 14, 15, 16, 1990.

- Yasser A. Hosni, Chin H. Lee, (UCF), Timothy S. Barth, and Cedric Hill, (NASA-KSC); "Ergonomically Designed Workstand for Overhead Operations: Case of Heat-Tile Replacement in the Space Shuttle"; Human Aspects of Advanced Manufacturing and Hybrid Automation, 2nd International conference; Honolulu, Hawaii, August 12-16, 1990.

- Yasser Hosni (UCF), Tamim Hamid (Lockheed); "Speech Recognition and Synthesis, Training and Implementation Strategies"; Human Aspects of advanced Manufacturing and Hybrid Automation, 2nd International conference; Honolulu, Hawaii, August 12-16, 1990.

- Yasser A. Hosni, John Creech (UCF), Timothy S. Barth, and Cedric Hill, (NASA-KSC); "Workstand Design for Overhead Operations; Case of Heat-Tile Replacement in Space Shuttle"; 1990 International Industrial Engineering Conference; San Francisco, CA, May 20-23, 1990. (Pending).

- Presentation: "Ergonomic Workstation for Overhead Operations" Innovation 91. The 4thd Annual Conference of Universities, Industry, Entrepreneurs & Government for Joint Technology Commercialization. Evaluated for Innovation 90, however will be considered for Innovation 91 upon completion of prototype.

- Yasser A. Hosni, Daniel Nasser, Jueng-Shing Hwang, and Labiche Ferreira; "Non-Contact, 3-D, Object Digitizing Systems for Die-Manufacturing"; Paper submitted for the 1990 Society for Integrated Manufacturing Conference, San Antonio, Texas, October 28-31, 1990.

VOICE DATA ENTRY (VDE)
Training and Implementation Strategies

Case Study

by

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University of Central Florida, Orlando, Florida 32816

Abstract

Current effort at Kennedy Space Center (KSC) involves implementation of voice data entry in the thermal Tile Processing System (TPS). Large amounts of data collection and recording along with the advancement in voice recognition and speech synthesis justified the introduction of a voice data entry system in support of TPS.
This paper presents a training and an implementation strategies for the VDE System in TPS at KSC. Training Strategies are tailored to different levels of the target population with varying objectives for the training sessions. Training scenarios and training manuals are designed to support the objectives of each session. A unique feature of the VDE is the fact that the "system" also needs to be trained for specific users.

Implementation strategy calls for parallel implementation for the current manual system over a period of four consecutive missions. This would be followed by gradual phasing out of the current manual system and phasing in of the VDE system over a span of three missions.

The methodologies used and the developed strategies can be used for the introduction of new technologies in general, and that related to voice and speech recognition in particular.

Introduction

The Tile Automation System (TAS) at Kennedy Space Center (KSC) includes the applications of automation, robotics and other advanced technologies to the shuttle Tile Processing System (TPS). The Voice Date Entry System (VDES) is one of the promising technologies currently under consideration. In one such application large measurement data for thermal tile needs to be collected and recorded in computer data bases. The system makes use of advances in the field of voice synthesis and speech recognition. It allows a technician to verbally input data directly into a computer. The technician is prompted by a speech synthesis module. The audio interaction between the computer and technician eliminates the need for a keyboard and video display during computer data input. The VDES frees the technicians hands to possibly perform the measurement and the eyes to read the measuring device. The traditional computer input/output devices are replaced in the VDES by a portable headset containing a microphone and speaker.

Successful implementation of the VDES requires training of the system to recognize the user's voice and speech as well as training the user to work with the system. This requires the development of a training and implementation strategies to insure acceptance of the system by its users, integrity and accuracy of data and give enough time for system testing.

The objective of this paper is to present training and implementation strategies for VDES currently under consideration at KSC in support of what is currently a manual operation.

The training and implementation module presented in this paper can easily be adapted to other VDES applications, once the proper application software is developed.

The first application of the VDES is in the "step and gap" measurement process which is vital to the assurance of high quality for the TPS. In this process, tiles must be measured for step (differential between adjacent tiles) and gap (clearance between tiles), when work is done that may alter these parameters such as tile replacement, tile removal and door and access panel opening. These measurements are made after any work involving the tile, has been performed.

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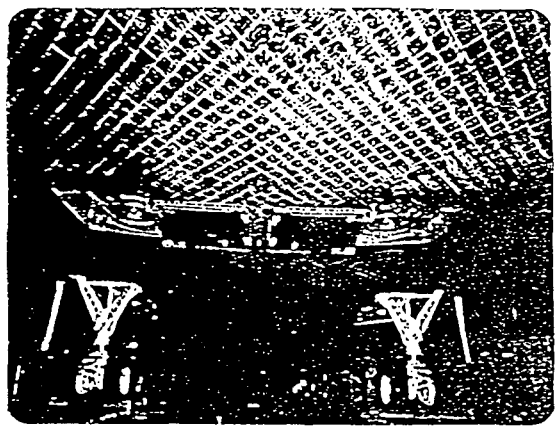

Figure 1. Thermal tile on the space shuttle.

In a study to asses the benefits of the VDES, it was found that the time for the step and gap processing can be reduced from 173 minutes to 43 minutes per tile if VDE is used. The time savings result from the greatly reduced data entry and evaluation times. Those savings become even larger for larger sets of tiles due to the constant set up times associated with the VDES. Figure 1. is a picture for the space orbiter depicting the possible large amount of data required to be collected and entered in the data base.

Other factors contributing to the improvement in the process include:

1. The elimination of recording measurements on paper.
2. Enhancement of the accuracy and verification of data.
3. Reduction in the skill requirement associated with typing.
4. The VDES can be interfaced with automated measurement tools to decrease the required time for measurement.

The voice entry may have other applications in KSC where there is a need for computer human interaction involving data transfer in a fast manner with hands free environment. Possible areas of application are: warehousing, dispatching, and office operations.

System Description:

The current voice data entry system at KSC consists of: input/ output interfaces, computer processors, voice synthesis and voice recognition hardware, and the associated cables and busses. The input/output devices are headphones with boom microphones. These may be replaced by in the ear microphone/ earphones in the future due to the possibility of more accurate recognition and increased durability. Presently the VDE system is networked via hardwire in the Orbiter Processing Facility (OPF).

Two kinds of computer systems are linked to serve the VDES. A DEC Micro VAX 3200 is on site at processing facility on the mezzanine level. Both MicroVAXes are linked by Ethernet to a DEC-VAX 8600 located remote from the OPF. DEC servers linked by RS 232 to the MicroVAXes are the interface between the MicroVAXes and the voice recognition and synthesis equipment. The voice synthesis equipment consists of DEC rack mounted DECTALK speech synthesis units. International Voice Products rack mounted model 4500 voice recognizer are currently used for voice

Due to the rapid prototyping philosophy used in the implementation of VDE the hardware is subject to change as better alternatives are found by iterative testing of currently used hardware.

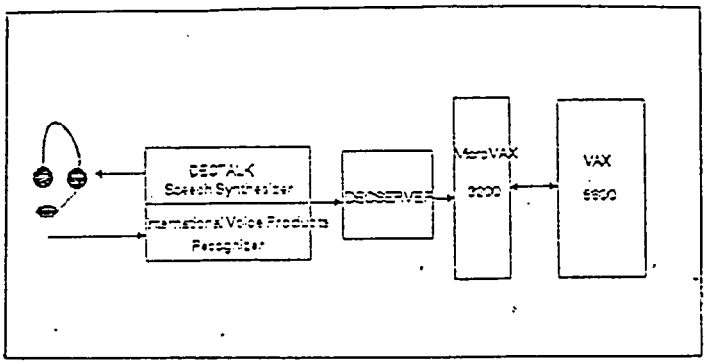

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Figure 2. Elements of the VDES

Software Description:

There are two types of software involved in all VDE systems:

1. The voice recognition and synthesis software--usually supplied by the system developer.

2. The main application program--developed based on the application.

Data extracted through the application program is stored, in real time, in a relational database to be accessed and processed by the VDE software. The software that is contained within the VDE system is comprised of a grammar file, translation table and voice response sections. The application program is written in a high level language identifying the sequence of operations, points of message interaction, and the data bases for which input will be directed once identified and translated to ASCII.

Training Strategy

Training Environment:

The VDES at KSC uses speech synthesis, as the prompt and voice entry as the response. When executing a training pass, the speech synthesizer prompts the technician to say an utterance and the technician responds using voice data entry. The rejection/acceptance is controlled by a training supervisor (trainer) who monitors the training pass by listening to the trainee over a headset.

The technicians will be located in a simulated work environment similar to the OPF set up, whereas the training supervisor and the voice equipment are located in another adjacent room. Therefore, the technician has no access to a terminal for the training sequences. The headset is hardwired to the voice equipment.

The current system requires 3 passes of voice training. The vocabulary in this application consists of 96 words and takes about 2 hours per pass. Training takes place in a simulated quiet environment in the first pass and subsequent passes take place in the actual work place.

The data that is to be used in the training scenarios is of alpha-numeric nature. The software also requires "yes," "no," "repeat," and other types of responses.

Strategy outline:

The strategy to be used in training potential users of the VDES is classified based on the user's categorization (technician, trainer, quality inspector, and supervisor). For each category the strategy is outlined as:

1. Target Population: In this section the typical trainee in the category is identified.
2. Objectives: Specific objectives expected to be fulfilled if a trainee completed the training sessions.
3. Equipment and training aids: Necessary equipment and training aid required for the training scenarios.
4. Methodology: Detailing the set-up of the training sessions.
5. Procedure: Step-by-step description of the training session(s), procedure to follow, and the sequence of scenarios.
6. Measure of training effectiveness: The trial "test" measuring the accomplishments, by trainee to the objectives.

Due to space limitation in this publication, only a summary of the tile technician's strategy is presented here.

Strategy for TPS Technician:

Target Population:

The target population for this training segment consists of TPS technicians certified for step and gap measurement and evaluation.

Objectives:

The objectives of this training are:

1. Introduce the technician to the VDES and its benefits.
2. Train the technician to set up and take down equipment.
3. Train the system to recognize the trainee voice.
4. To use the VDES to produce a computer generated report with no errors under normal working conditions.

Equipment:

1. VDES equipment (hardware and software) to be used on the job.
2. The application software.
3. Technician training manual. (Developed as a separate document)
4. Step and gap case studies. (Developed as a separate document)

Methodology:

The training consists of five approximately two-hour segments to be given on different days over the span of two weeks. The first segment starts with an overall description of the system to introduce the technicians to the VDES and its benefits. At the beginning of this session the trainee will be provided with a document containing system description, the benefits associated with using the system, the user vocabulary and the software description. Except for the short introductory segment, the first three sessions will be used mainly to provide the system with voice patterns for the technician. These sessions will require a one-to-one technician to trainer ratio. The fourth and fifth sessions will be used to train the technician on the use of the application software and to generate the report under normal working conditions. The case studies provide the same information that would be available to the technician using the usual in the work environment such as step and gap measurements, tile numbers and spatial relations.

Procedure:

Step by step description of the methodology over 5 sessions and the point of use of each case study in the scenario.

Measure of proficiency:

- Successful set up of the system without trainer interference
- Completeness of three reports with no errors.

These training scenarios should provide the technicians with a sufficient understanding of the VDES and the application software to incorporate all required items into their work. The TPS technician should become proficient in using the VDES for step and gap data entry.

Implementation Strategy

Based on the analysis of the situation, we recommend a combination of gradual and parallel methods for the KSC operation. This method will be called Parallel/Gradual combination strategy. A parallel implementation plan will be initiated for four mission flows after training half the target population in the technicians and quality inspectors categories to be followed by the gradual implementation over 3 to 4 flows before cut-off of present system. Figure 3. is a graphical representation of the recommended strategy.

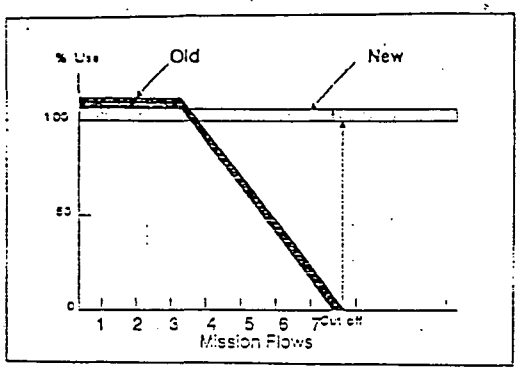

Figure 3. Parallel/Gradual Implementation

Justification for this strategy is motivated by the following:

1. The current application software have not been tested thoroughly.
2. Problems associated with some safety constraints such as non hardwire communication between system components have not been resolved yet.
3. Parallel implementation for 4 flows will allow "on the job" testing of the system and training system users.
4. It is recommended that system developers use the parallel plan of the strategy to compare data recorded by both systems and make the necessary corrections in the application software.
5. The gradual phase of the strategy will allow other potential users the opportunity to appreciate the benefits of the system and break the psychological barrier associated with introduction of new technologies.
6. A period of 7 to 8 flows may allow time for new developments and voice technology to be incorporated in the VDES.

Conclusion

Speech recognition and voice synthesis is a high promising technology for increasing productivity in a variety of applications. Pioneering in these applications are operations requiring interaction with computers while freeing the hands and the sight (usually required for interaction) to perform other tasks. The tile processing of the Space Orbiter at KSC is a prime candidate for the use of voice systems.

System use requires training both the "system" and its "user" for successful application. The system has to be trained on the recognition of all operation "vocabulary" , while the user needs to be trained on the system operation. Training may be conducted in simulated environment in the first few sessions, however, it needs to take place in the operational environment for the majority of the sessions.

Implementation of voice system needs to parallel the existing system for a period of time until the system is free of errors, and enough users are trained on its use. This to be followed by gradual phasing out of the old system and phasing in of the Voice System. The length of parallel and gradual implementation periods varies according to the criticality of the operation.

Like any new technology, bar coding for example, introducing voice technology will face the traditional resistance to change by its potential users. However, once the benefits of its use are realized, voice systems are expected to become the norm in a variety of operations.

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Biographical Sketch

Dr. Yasser Hosni is currently a Professor at the College of Engineering, University of Central Florida. His interest in industrial software engineering and computer based systems began when he worked as a software specialist with NCR Company in 1970, before obtaining his Ph.D. in Industrial Engineering in 1976 from the University of Arkansas, and joining the faculty at UCF. Dr. Hosni worked in industry for a number of years where he gained hands on experience in industrial applications. He taught courses in industrial engineering, quantitative techniques, software and information systems. His research interests include: software design for engineering applications, and the development of industrial computer based applications. He is currently involved in a productivity study with NASA-KSC aimed at introducing new technologies for the shuttle processing at KSC. He is a senior member of IIE, member in IEEE, ASEE, and SOLE.

Tamim S. Hamid is currently a graduate student at the University of Central Florida, studying in the areas of Computer Integrated Manufacturing. He obtained his B.Sc. in Industrial Engineering from University of Missouri at Rolla in 1986. His work experience at Lockheed Space Operations at the Kennedy Space Center entailed incorporating new technologies for NASA Space Shuttle. His areas of expertise include Voice Recognition and Synthesis, Robotics and Expert Systems.

DESIGN OF A WORKSTAND FOR OVERHEAD OPERATIONS: CASE OF THE SPACE SHUTTLE HEAT-TILE REPLACEMENT

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SUMMARY

Operations conducted on the space shuttle at Kennedy Space Center (KSC) involve tasks such as orbiter heat tile inspection, repair, and replacement. Although tile and other thermal protection material are used on the entire orbiter exterior, work involving the lower surfaces is the most challenging to the tile technicians since a great deal of work is done "out of position" i.e., upside down.

Access to the lower surface tile is achieved from floor level by using various designs and sizes of workstands, some portable, some not. Most often, one or two technicians are involved in a given task.

Presented in this paper is a design of a seat to be installed on a workstand for overhead tasks. The design considers ergonomic factors dealing with upper body support for the technician when performing the task in less than optimal position. Other factors are practical in nature such as portability, access to full circumference of the work platform, and height adjustability to permit optimal positioning of workstand for access to all tile on the lower surfaces for the orbiter.

INTRODUCTION

The NASA/KSC, and the University of Central Florida (UCF) are presently investigating improvements in the design of workstands used in performing tasks related to the repair and maintenance of the Thermal Protection System (TPS) on the Space Shuttle Orbiter vehicles. The overall objective of the study is to expedite repairs and to improve the accuracy with which these repairs are accomplished.

TPS maintenance is performed after each flight on all external surfaces of each of the orbiters, as well as in the payload bays. However, since most damage to the TPS is sustained on the lower and flight control surfaces, particularly in the aft section, the research team is restricting its study to maintenance tasks performed from stands positioned on the shop floor.

The configuration of the orbiter and the tasks performed on it (study limited to lower and flight control surfaces) require that virtually all processes be performed in non-standard work positions, that is, overhead.

The literature searched indicates that there is little data available on task performance in these postures. In fact, the postures and positions assumed are not recognized as anthropometrically acceptable for precision work when considering the limits of human reach and vision. It is evident that technician performance may be degraded by problems associated with visibility of the work area and fatigue brought on both by working in less than optimal postures, and in elevating the eyes and rotating the neck backward to view the work area. Further, the work positions assumed by technicians, and the mobility/adjustability of the stands have significant safety implications.

WORK ENVIRONMENT

Processing of the TPS of the orbiters is unique in the aerospace industry due to several conditions existing in the Orbiter Processing Facility (OPF) environment, the design of the orbiters themselves, and the nature of the tasks accomplished. Following are some characteristics of the work environment which may affect workstand design.

1. The thermal tile are easily damaged by contact with equipment, tooling, workstands, or the skin of the technicians.

2. Many maintenance activities, both on the vehicle and the tile, are performed simultaneously; hence, the work area is typically crowded by personnel, equipment, and workstands of various designs. All of these obstacles must be "worked around." Figure 1. shows the working place around the orbiter, ready for maintenance operations.

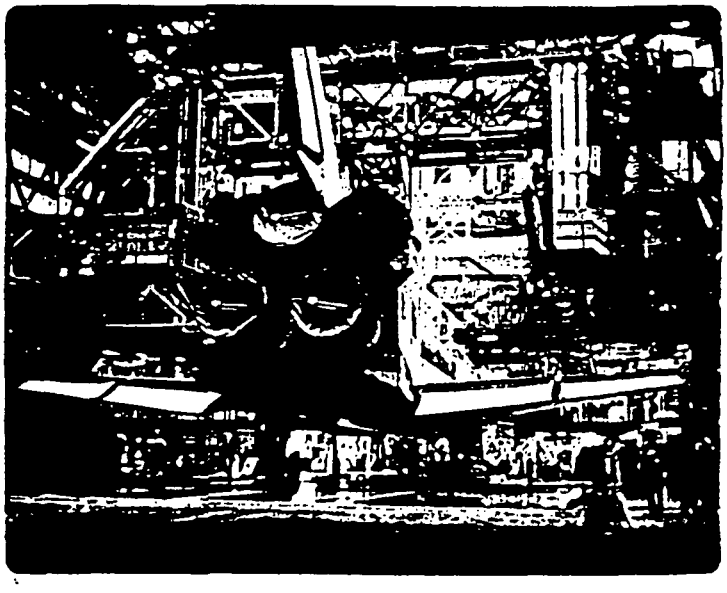

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Figure 1. Work area in the OPF

3. The environment is restrictive in the materials and designs that can be used in the construction of the workstands. Primary restrictions concern the flame spread rate and out-gasing under fire conditions of the materials used in construction, as well as the mobility of the stands and the level of cleanliness that must be maintained.

4. Repair or replacement of TPS components requires extreme precision in most cases, dictating that the stands be rigid and stable, when work is performed.

5. Most tasks are presently performed in out-of-position postures, that is overhead. New stand designs should minimize fatigue complications in these postures.

6. The maintenance processes vary significantly in the surface area that is covered in accomplishing them. Repair of individual tile and removal and/or bonding of new tile is typically restricted to an area of one square foot. Measuring of the step and gap between several tile may typically have the technician traversing areas of several feet.

7. Most of the processes accomplished in TPS maintenance require the labor of only one person. However, all processes are inspected and approved by quality control and engineering personnel at numerous stages. Hence, ingress and egress from the working/inspection position must be accomplished easily and quickly.

8. Task accomplishment is heavily dominated by documentation and referral to written procedures--there must be immediate and easy access to paperwork and manuals.

DESIGN CRITERIA

1. The workstands must provide easy access to the lower surfaces of the orbiters which range from 8 to 12 feet from the shop floor in the OPF. Male and female technicians of normal height ranges use the stands.

2. The workstands should have infinite height adjustment to accommodate the range of height of the work areas, as well as the range of height and reach of the technicians. The stands' height should be easily adjustable by one person, and preferably would be adjustable from the technician's working position.

3. The design should provide postural support for the technicians in accomplishing overhead processes thereby minimizing the effects of fatigue and visibility of the work area.

4. It is recommended that the use of electrical and/or hydraulic power use be minimized for safety reasons, i.e. cables, hoses, etc., should not be extended around the orbiter on the floor of the work place. Manually powered devices is a recommended substitute.

5. If wheels are to be used on the workstands it should be of large enough diameter to allow easy passage over floor gratings used to cover equipment chases and drainage channels.

6. Proof testing - stands should be able to withstand static loadings of 375 lbs. for each person that they will accommodate without failure or significant deformation. Handrails should be able to withstand loadings of 375 lbs. applied downward at a 45 degree angle from vertical Steps and/or ladder rungs should be able to withstand static loading of 375 lbs.

7. The design of the workstand must conform to NASA standards for Space Shuttle Ground Support Equipment General Design Requirements.

8. Materials used in construction must conform to NASA standards for materials permissible for use in the OPF.

9. Human engineering criteria should conform to the military standards for Military Systems, Equipment and Facilities.

WORKSTAND DESIGN

The design strategy for the modified or new workstand is directed at increasing technician safety, decreasing the time to perform TPS processing tasks, and increasing the precision with which these tasks are accomplished.

All current and any added alternatives have, or should have, four elements included in their design:

1. The use of larger and wider wheels - minimum of 8" diameter and 2.5" width, to permit easy rolling over obstacles and zero penetration of the floor gratings.

2. Improvements in the range and ease of height adjustments.

3. Improved access to equipment and paperwork.

4. Features to allow the technician to work in a semi-reclined seating position, or as an alternative, provision for upper body support when standing while leaning backward.

The first three elements are essential. The fourth, reclining the technician, may not prove beneficial for tasks performed that traverse large areas, but should be considered essential for tasks limited to small areas such as repair of one or a few tiles, or cavity preparation and/or tile bonding to the surface of the orbiter.

Due to the space limitation in this paper, we are reporting on the design of "seat to be added to an existing workstand which is currently being used at KSC. Figure 2.a is the current workstand and the suggested location for the seat assembly. The design makes use of the unused "volume" under the stand platform in housing the seat assembly. In situations where there is a need for an operation requiring positioning of operator for long periods of time performing an overhead operation, the platform would be opened and the seat assembly would be raised to the platform level when it is to secured. Figure 2.b. shows the elements of the seat assembly, when a height adjustable mechanism (powered manually or mechanically), can raise a seated worker to the proper position underneath the orbiter. The seat is equipped with a rotating subassembly table to allow coverage of an area and it is in the proper position. The operator can then lock the table in a certain position.

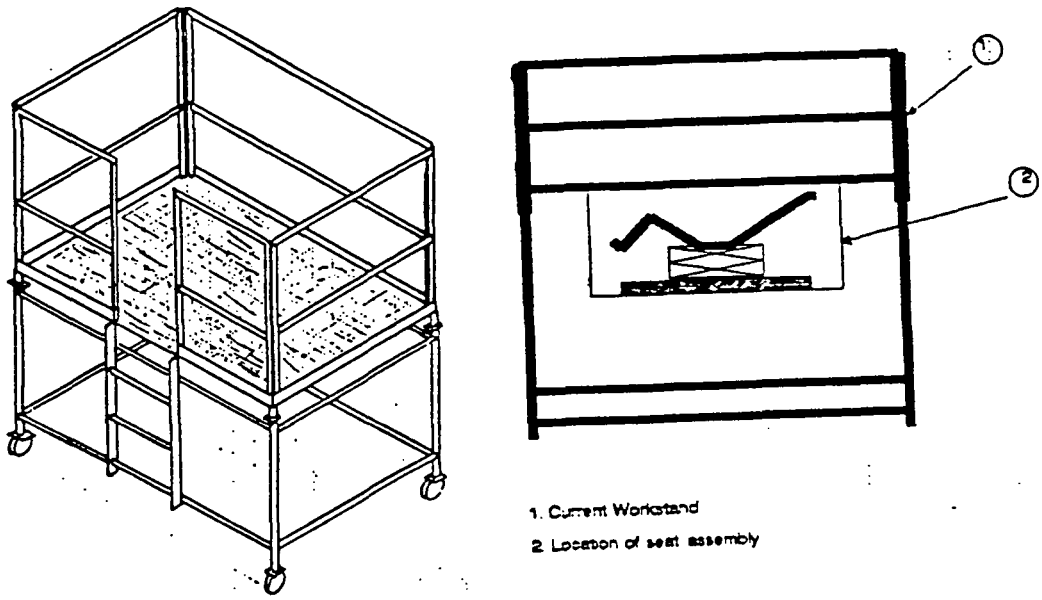

Figure 2.a.
Current Workstand and suggested location for the seat assembly.

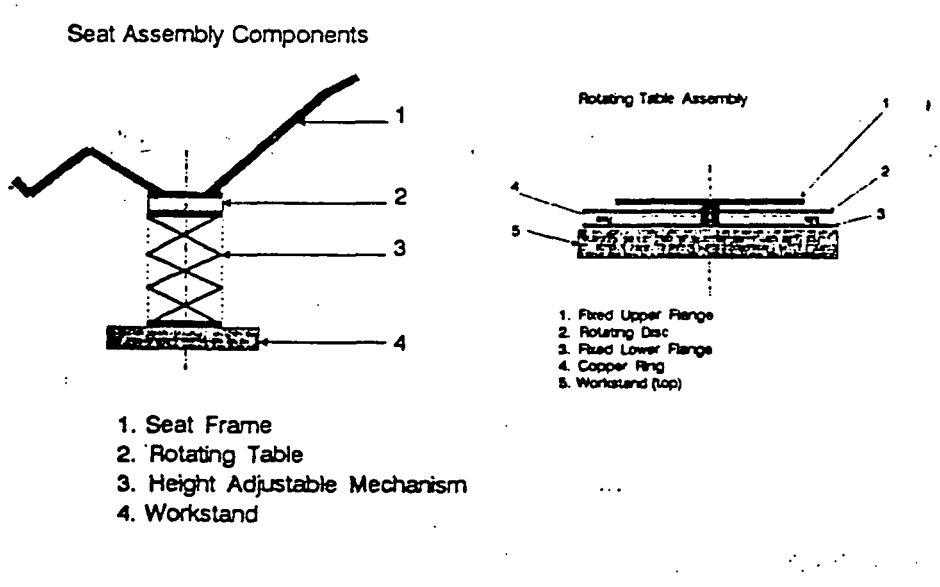

Figure 2.b.
Elements of the seat subassembly

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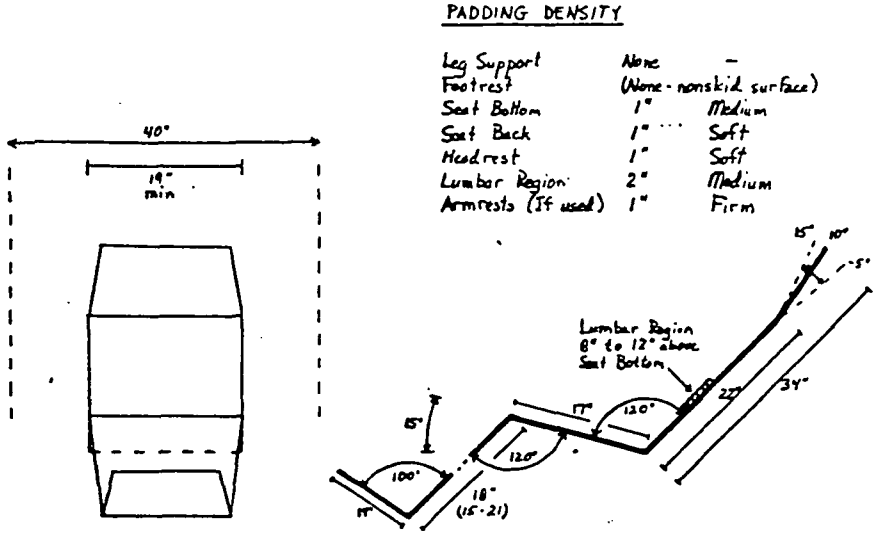

Figure 2.c.
Seat Dimensions.

Figure 2.c. is detailed drawing of the seat dimensions. It is a compromise of several criteria, but generally follow the guidelines for the average adult (lengths, angles) so as to accommodate the range of sizes for the technician population (Human scale, IE Handbook, MIL-STD-1472). Modifications may be made, but the following criteria should be adhered to:

1. With backrest angles in this range (120 degrees shown), a headrest must be used, and headrest height should not be less than 31".

2. Footrest angles should not allow knee flection of less than 100 degrees (110-120 optimum).

3. Seat bottom inclination should not be less than 15 degrees (shown) to prevent sliding downward. Angles greater than 15 degrees, if used, will make ingress or egress more difficult.

4. Footrest angle should not be less than 90 degrees (100 degrees shown).

5. Lumbar support should be maintained, via thicker padding or contouring of the backrest.

6. Knee to ankle distance should be adjustable over the range of 15" to 21".

7. Optimum headrest angle for reclined seating positions when viewing objects near the horizontal place is 10 degrees (shown). However, for this application where the technician is looking overhead, the headrest angle should be adjustable.

8. Seat width should not be less than 19" and hip clearance not less than 22".

9. Work area width should be unobstructed for a width of 40" to allow full arm movement.

CONCLUSION

The ergonomic design of a workstand should be based not only on anthropometric data but also specific requirements of the work itself and workers behavioral pattern. The space shuttle heat tile replacement represent an unique working environment with specific requirements.

This paper presented a workstand design based on the specific design criteria established for the TPS repair and maintenance tasks. As demonstrated in this paper, the general ergonomic guidelines for workstand design should be modified under practical conditions in order to improve its effectiveness. The present design can be adapted for other aerospace industries which have common problem with overhead operation.

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SPEECH RECOGNITION AND SYNTHESIS TRAINING AND IMPLEMENTATION STRATEGIES

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SUMMARY

Current effort at Kennedy Space Center (KSC) involves implementation of Voice Data Entry (VDE) in the Thermal Protection System (TPS). Large amounts of data collection and recording along with advancement in voice recognition and speech synthesis justified the introduction of a voice data entry system in support of TPS. The first stage includes training of potential users (technicians, quality controllers, and management supervisors). The next stage is the implementation of the system on the shop floor and the assessment of system performance. This paper reports on the training strategy, an implementation strategy, and initial observations for the VDE at KSC.

INTRODUCTION

During the initial design phase of the Thermal Protection System (TPS) of the shuttle, little consideration was given to optimizing the TPS design for operational maintenance efficiency. This has resulted in a TPS whose maintenance program can be characterized as being non-power intensive and time consuming. This is due to the fact that the TPS maintenance program uses manual techniques for inspection and measurement, mostly paper databases, no networking between pertinent electronic databases, manual scheduling of operational flows and a quality control and reliability program based on a paper information system. Introducing new technologies and operational concepts into a critical system, like the shuttle TPS, requires a careful assessment of the appropriate systems engineering approach. One module of the Tile Automation System (TAS) was the VDE Data Entry System (VDES).

Over the past decade productive speech recognition applications have been emerging to show slow but steady growth. The technology itself has improved sufficiently to provide for satisfactory operational performance, both in terms of accuracy and clear user benefits. Significant capabilities can now be more easily integrated into valuable widely used applications, especially at Kennedy Space Center. With the recent availability of powerful inexpensive memory and processors (at the PC level), high performance recognition has become more affordable.

VOICE APPLICATIONS

In a feasibility study to determine the types of jobs which lends itself to "voice" application, the following job characteristics were identified.

1. Interaction between the operator and a machine (computer) is required in performing the job tasks.
2. Simultaneous work by hands, while communicating with computer, i.e., the need for a free hand and sight environment.
3. Crowded workplace where it is difficult to house the computer and/or its peripherals (board, keyboard, screen, etc.) in the workplace (workstation).
4. The job requires relatively high typing skill, in an environment which may be short of this skill.
5. The job requires verification of any interaction with computer, such as consulting databases for technical specifics (tolerances, allowances, or any other criteria).
6. The vocabulary used in the interaction with the computer is limited and consistent.
7. Job is performed by operator (labor) who is stable on the job. Voice applications require training of the computer to recognize the speech of its user. The majority of the reliable voice systems are user dependent and the user, as well as the job, has to be permanent to justify the economic feasibility of voice systems.

In typical processes at KSC TPS, three areas of voice date entry has been identified.

First, the TPS quality control technician inspects the thermal protection system after each flight using voice data entry to identify anomalies. The inspector voices in the part number, the dimensions of the anomaly, and other necessary data which then produces an automated problem report in the central database. Second, the problem report is dispositioned by the TPS engineer using keyboard entry to identify the proper repair procedures for the particular anomaly. The problem report then proceeds through an electronic signature loop until final approval. Third, the TPS technician uses voice data entry to buy-off each work instruction and enter work control data. On specific work instructions, the TPS technician will also use automated instrumentation such as laser sensors to scan the tiles for critical dimensions of step and gap measurements between adjacent tiles.

SYSTEM DESCRIPTION

The current voice data entry system at KSC consists of: input/output interfaces, computer processors, voice synthesis and voice recognition hardware, and the associated cables and busses. The input/output devices are headphones with boom microphones. These may be replaced by in the ear microphone/earphones in the future due to the possibility of more accurate recognition and increased durability. Presently the VDE system is networked via hardwire in the Orbiter Processing Facility (OPF).

The voice synthesis equipment consists of DEC rack mounted DECTALK speech synthesis units. International Voice Products rack mounted model 4500 voice recognizer are currently used for voice. Figure 1. shows the elements of the Voice Data Entry.

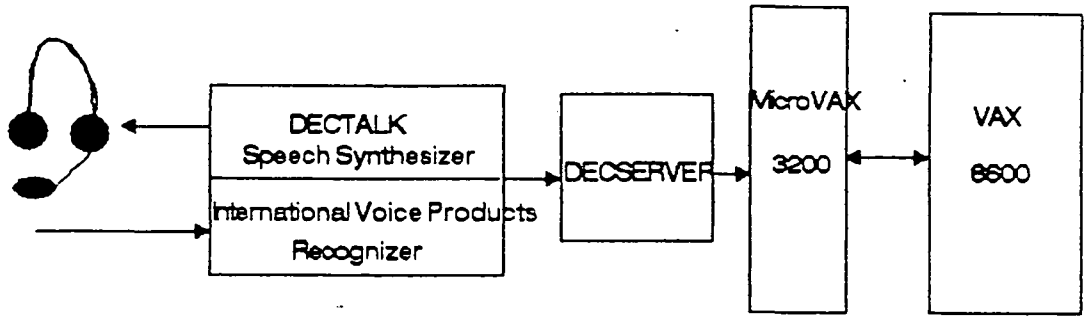

Figure 1. Elements of the VDES

There are two types of software involved in all VDE systems:

1. The voice recognition and synthesis software--usually supplied by the system developer.
2. The main application program--developed based on the application.

Date extracted through the application program is stored, in real time, in a relational database to be accessed and processed by the VDE software. The software that is contained within the VDE system is comprised of a grammar file, translation table and voice response sections. The application program is written in a high level language identifying the sequence of operations, points of message interaction, and the data bases for which input will be directed once identified and translated to ASCII.

TRAINING AND IMPLEMENTATION STRATEGIES

Training Strategy:

Environment:

When executing a training pass, the speech synthesizer prompts the technician to say an utterance and the technician responds using voice data entry. The rejection/acceptance is controlled by a training supervisor (trainer) who monitors the training pass by listening to the trainee over a headset.

The technicians will be located in a simulated work place similar to the OPF set up, however in a quieter environment, whereas the training supervisor and the voice equipment are located in another adjacent room. Therefore, the technician has no access to a terminal for the training sequences. The headset is hardwired to the voice equipment.

The current system requires 3 passes of voice training. The vocabulary in this application consists of 96 words and takes about 2 hours per pass. Training takes place in a simulated quiet environment in the first pass and subsequent passes take place in the actual work place.

The data that is to be used on the training scenarios is of alpha-numeric nature. The software also requires "yes," "no," "repeat," and other types of responses.

Strategy outline:

The strategy to be used in training potential users of the VDES is classified based on the user's categorization (technician, trainer, quality inspector, and supervisor). For each category the strategy is outlined as:

1. Target Population: In this section the typical trainee in the category is identified.
2. Objectives: Specific objectives expected to be fulfilled if a trainee completed the training sessions.
3. Equipment and training aids: Necessary equipment and training aid required for the training scenarios.
4. Methodology: Detailing the set-up of the training sessions.
5. Procedure: Step-by-step description of the training session (s), procedure to follow, and the sequence of scenarios.
6. Measure of training effectiveness: The trial "test" measuring the accomplishments, by trainee to the objectives.

Due to space limitation in this publication, only a summary of the tile technician's methodology is presented here.

Methodology for training a tile technician:

The training consists of five approximately two-hour segments to be given on different days over the span of two weeks. The first segment starts with an overall description of the system to introduce the technicians to the VDES and its benefits. At the beginning of this session the trainee will be provided with a document containing system description, the benefits associated with using the system, the user vocabulary and the software description. Except for the short introductory segment, the first three sessions will be used mainly to provide the system with voice patterns for the technician. These sessions will require a one-to-one technician to trainer ratio. The fourth and fifth sessions will be used to train the technician on the use of the application software and to generate the report under normal working conditions. The case studies provide the same information that would be available to the technician using the usual in the work environment such as step and gap measurements, tile numbers and spatial relations.

These training scenarios should provide the technicians with a sufficient understanding of the VDES and the application software to incorporate all required items into their work. The TPS technician should become proficient in using the VDES for step and gap data entry.

Implementation Strategy:

Based on the analysis of the situation, it is recommended that a combination of gradual and parallel implementation for the KSC operation. A parallel implementation plan will be initiated for four mission flows after training half the target population in the technicians and quality inspectors categories to be followed by the gradual implementation over 3 to 4 flows before cut-off of present system. Figure 2 is a graphical representation of the recommended strategy.

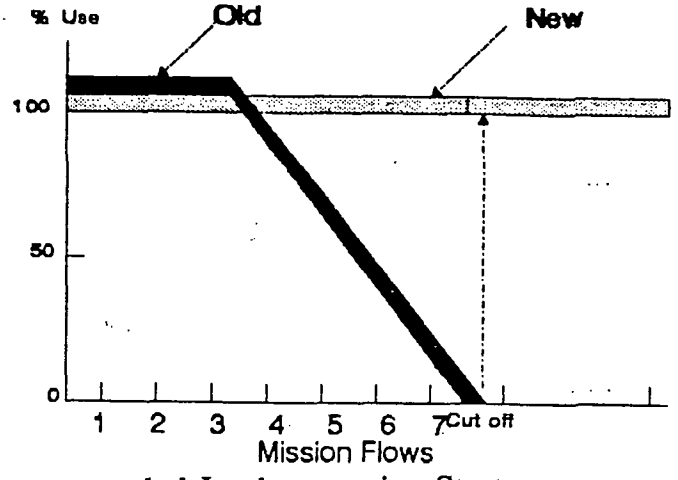

Figure 2. Recommended Implementation Strategy

Justification for this strategy is motivated by the following:

1. The current application software have not been tested thoroughly.
2. Problems associated with some safety constraints such as non hardwire communication between system components have not been resolved yet.
3. Parallel implementation for 4 flows will allow "on the job" testing of the system and training of the system users.
4. It is recommended that system developers use the parallel plan of the strategy to compare data recorded by both systems and make the necessary corrections in the application software.
5. The gradual phase of the strategy will allow other potential users the opportunity to appreciate the benefits of the system and break the psychological barrier associated with introduction of new technologies.
6. A period of 7 to 8 flows may allow time for new developments and voice technology to be incorporated in the VDES.

LESSONS LEARNED

Training time needs to be quality time. In the preliminary training sessions first passes were found to be critical. The quiet environment training proved to be invaluable. As the technician advanced to the working environment, the noise-cancelling microphone became a crucial piece of equipment. The ambient noise in a shuttle processing environment has a considerable noise spike levels. During training, the paging system in the Orbiter Processing Facility (OPF) caused recognition errors since paging is in the same frequency range as the voice input. It was important to have no paging during training and also not to test recognition while the paging system was in use. Irregular background noise is more disruptive to recognition than constant noise.

During remote training, speech impediments will become noticeable to the trainer. If a user pronounced a particular word inappropriately, it is difficult for the trainer to determine whether the user heard the speech synthesizer incorrectly or the user is unable to correctly pronounce the word. Also, since the speech synthesizer prompts the user in a monotone voice, some users altered their method of speaking in order to conform with the speech synthesizer's lack of inflection. When the system is in operational use, the user speaks naturally. Therefore, some problems were incurred with recognition due to lack of consistency during training. When performing regular training or remote training a script of the utterances is recommended in order for the user to concentrate more on the utterances rather than relying on the trainer for assistance. This familiarizes the trainee to input data from text to speech, whereas speech to speech sometimes results in mimicking of the synthesized voice and no thought is given to their own speech pattern. Another reason to use a script during remote training is that the user has to remember what the synthesizer said and repeat it. This becomes difficult for the user if the utterance is more than four words. This value fluctuates depending on the type of utterances. Users with bad recognition due to colds or variance in some utterances have the ability to perform a retrain session in real time. This results in good recognition and more importantly, the users have the control to retrain words they feel gives them trouble. This involvement in retraining allows the users to critique themselves and continuously sustain an acceptable recognition level.

Unusual synthesized voices appear to have a better effect on training than with normal voices or pleasant voices. Trainees tend to mimic the voices and do not truly talk in their natural voice pattern.

Training sessions for users should not be lengthy or monotonous. User motivation drops considerably as training sessions are prolonged. Designers and application engineers should consider training time in choosing the vocabulary for the application and design the grammar structure to contain a minimum number of samples or models of each utterance. Training sessions should be limited to a time agreeable to the user and the trainer. Users should be alert when performing training. If this is not achieved, operational use of the VDES will be greatly affected. Due to stress and other attributes, the voice patterns can change. A relaxed user during training will not be always relaxed during working conditions and vice versa. Users of the voice recognition should be made aware of their concentration level when input data. Basically, the user should be aware of the grammar structure and their own speaking volume, pitch, and pattern. Also, similar problems found in regular voice training were found in remote training. For example, poor training can result in insertion errors, nonrecognition, and misrecognition.

The user should be very familiar and comfortable with the software. To accomplish this, the users were trained on the software in front of a terminal so they could see the interaction between their voice and the software. This was found to be very critical because the user does not have access to a terminal in the working environment. Users that did not have this training had a very difficult time conceptualizing this interaction. Any indication of uncertainty of the software will be seen in the performance in recognition.

Use of a mobile transmitter and receiver with headset allows the unrestricted movement by the user within the OPF. Operationally, the effective range of the system is the limiting factor in determining how far an auditor may travel from the base unit and still function with a user acceptable level of recognition error. With this fact, our test experience indicates that the environmental characteristics of the structure in which the system is being uses in combination with the level of ambient RF noise, are key parameters affecting useful range.

CONCLUSION

Speech recognition and voice synthesis is a high promising technology for increasing productivity in a variety of applications. Pioneering in these applications are operations requiring interaction with computers while freeing the hands and the sight (usually required for interaction) to perform other tasks. The tile processing of the Space Orbiter at KSC is a prime candidate for the use of voice systems.

System use requires training both the "system" and its "user" for successful application. The system has to be trained on the recognition of all operation "vocabulary", while the user needs to be trained on the system operation. Training may be conducted in simulated environment in the first few sessions, however, it needs to take place in the operational environment for the majority of the sessions.

Implementation of voice system needs to parallel the existing system for a period of time until the system is free of errors, and enough users are trained on its use, this to be followed by gradual phasing out of the old system and phasing in of the Voice System. The length of parallel and gradual implementation periods varies according to the criticality of the operation.

Like any new technology, bar coding for example, introducing voice technology will face the traditional resistance to change by its potential users. However, once the benefits of its use are realized, voice systems are expected to become the norm in a variety of operations.

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BIOGRAPHICAL SKETCH

Dr. Yasser Hosni is currently a Professor at the College of Engineering, University of Central Florida. His interest in industrial software engineering and computer based systems began when he worked as a software specialist with NCR Company in 1970, before obtaining his Ph.D. in Industrial Engineering in 1976 from the University of Arkansas, and joining the faculty at UCF. Dr. Hosni worked in industry for a number of years where he gained hands on experience in industrial applications. He taught courses in industrial engineering, quantitative techniques, software and information systems. His research interests include: software design for engineering applications, and the development of industrial computer based applications. He is currently involved in a productivity study with NASA-KSC aimed at introducing new technologies for the shuttle processing at KSC. He is a senior member of IIE, member in IEEE, ASEE, and SOLE.

Tamim S. Hamid is currently a graduate student at the University of Central Florida, studying in the areas of Computer Integrated Manufacturing. He obtained his B.Sc. in Industrial Engineering from the University of Missouri at Rolla in 1986. His work experience at Lockheed Space Operations at the Kennedy Space Center entailed incorporating new technologies for NASA Space Shuttle. His areas of expertise include Voice Recognition and Synthesis, Robotics and Expert Systems.

IMPROVING PRODUCTIVITY OF SPACE SHUTTLE PROCESSING

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NASA - Kennedy Space Center

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ABSTRACT:

This paper will describe a multi-year collaborative effort between NASA, some of NASA's subcontractors, and the Department of Industrial Engineering and Management Systems of the University of Central Florida. The objective of the effort is to improve the productivity (e.g. reduce manpower and time, increase quality and reliability) of processing the thermal protection system of the orbiter between successive launches.

The effort consists of four distinct thrusts: Training and the implementation strategies for a voice activated computerized data collection system to reduce the paperwork load of technicians; a design effort to develop an ergonomic workstation for the overhead operations involving heat protection title replacement; a photo-mechanics experimentation to use lasers and/or photomechanics to digitize the shape of tile cavities and link this with a computer controlled machining process to automate the manufacture of replacement heat tiles, and a human performance productivity study aimed at developing an incentive system based on standards and rewards.

The effort is aimed at achieving a substantial reduction in the current requirement of 160 man/hours per replacement heat tile, together with better quality and reliability in both tile replacement and paperwork accuracy.

INTRODUCTION

Processing of the Shuttle Thermal Protection System (TPS) at Kennedy Space Center (KSC) accounts for a substantial portion of the cost and time of any space mission. Delays, inaccuracies, deviations, and irregularities may add significantly to this costs. Operator fatigue, personal injuries and damage to ground support equipment and the orbiter can make these costs increase substantially or delay a critical program to a point where it may become infeasible to continue. A large portion of current TPS operations are labor intensive. Due to the complexity of tile processing operations and the high degree of labor intensiveness, tile operations require long periods of time to accomplish as well as uncomfortable positioning of operators during processing. It is estimated that the currently up to 120 man hours maybe required to replace a damaged tile. It is anticipated that TPS activities will be a contributing limiting factor in determining future flight roles as well as the rate of which space experiments and activities can take place.

Initial assessment of tile processing operations at KSC shows promising areas for improvement. Such improvements should contribute to cost reduction and, more reliable and efficient operations in the TPS. On the other hand, the impact of such improvement and the effect of automation on productivity, operator performance, and morale requires study from the human engineering point of view.

In a cooperative agreement between the University of Central Florida (UCF), and

NASA - KSC, the department of Industrial Engineering and Management System (IEMS) started a research project entitled "Productivity Enhancement." The overall objective of this research project is to apply industrial engineering methods and techniques to appropriate areas of orbiter processing.

SCOPE OF THE STUDY AND APPROACH

Because of the wide range of operations at KSC, the scope of this study was limited to the productivity of tasks related to the repair, maintenance, and processing of the thermal protection system on the space shuttle orbiter vehicles. TPS processing is performed after each flight on all external surfaces for each of the orbiters, as well as in the payload bays. In a preliminary study conducted during the summer 1989 by the NASA - UCF the team selected four components for the project. The components were selected based on their potential effect on productivity and the availablity of resources to the team. These components are:

1. Resolve problems associated with the use of voice-data entry system (VDES) for data recording, and develop training and implementation strategies aimed at replacing the current manual data recording procedures.

2. Design an ergonomically improved workstand with greater stability, height adjustability and and tool storage to accommodate all proposed tooling and equipment.

3. Conduct a technical feasibility study for the use of photomechanics in support of digitization of tile cavities and link it with a computer controlled machine for the production of tile replacements.

4. Conduct a human performance productivity study aimed at examining the interface of personnel and new technology in the TPS processing. The initial effort would be directed towards identifying and prioriting road blocks to improved productivity, and establishing baseline performance measures utilizing current technology and equipment.

The estimated duration for this study is three years, with partial results to be reported at the end of each year (phase).

The approach for the first phase of this project includes formation of the research team from UCF and establishing contacts with KSC, and Lockheed-Space Operation Company (LSOC).

Major effort in the first phase include literature and vendors searches using UCF facilities, and conducting an assessment of current productivity and working environment in the TPS' work area. The first phase also include studying any existing systems, current methodologies, and any "approved for use" methods.

For each of the four components of the study, a graduate student with either

background or specialty in the area of study was teamed up with one faculty member to research the component and develop solutions. In the initial phase of the study a one page document was produced for each component detailing the objective, procedure to be followed, and the expected outcome of the study. Occasionally a team could be assisted by undergraduate students as part of their assignments in a senior design class in the industrial engineering program. The study required several visits per week by the research team to KSC facilities. The approach included meeting with NASA - and LSOC personnel, interviews with managers and tile technicians, and reviewing existing documentation.

INITIAL RESULTS

Since the study is in its first phase, only partial results (outcomes) are available. The degree of progress in each of the study components varies. In this section some of the outcomes which may have a high potential for increased productivity in each of the four components of the study will be presented.

Voice Data Entry System:

The Voice Data Entry System (VDES) is one of the promising technologies currently being studied at KSC. VDES is designed to replace the manual recording of large quantities of measurement data associated with the TPS. The system uses recent advances in the field of voice synthesis and recognition. It allows the technician to

verbally input data directly into a computer. The technician is prompted by a speech synthesis module. The audio interaction between the computer and technician eliminates the need for a keyboard and video display during data input. The traditional computer input/output devices are replaced in the VDES by a portable headset containing a microphone and speaker. There are a number of applications for the VDES in the TPS and other areas at KSC. One possible application of VDES is in the step and gap measurement process which is vital to the assurance of high quality for the TPS. In this process tiles must be measured and recorded for step and gap when work, such as tile replacement, tile removal and door and access panel opening, is performed, this work may alter the step and gap measurements. The expected time savings from the use of this technology from 173 minutes to 43 minutes per tile.

Successful implementation of the VDES requires training of the system to recognize the user's voice as well as training the user to work with the system. Introduction of the system to the shop floor requires an implementation strategy to insure data integrity and to allow for system testing.

The research team conducted vendor survey for voice entry systems. A micro-computer based system was selected for experimentation with a radio signal. The system was selected based on the amount of vocabulary which can be stored, its compatibility with the expected data type to be transferred between the user and a computer, and constraints related to the use of wire cables in the Orbiter Processing Facility.

Parallel to the above described effort a training strategy was developed for various levels of expected users (managers, technicians, quality control inspectors, and trainers). For each level a number of training scenarios were developed. Considerations were given in the scenarios to include typical cases which are representative of what may face the user.

The implementation strategy calls for gradual introduction of the system in parallel with the existing manual system for 4 flows (each orbiter processing sequence is referred to as a flow) and compare data entry methods, to be followed by gradual implementation for 3 to 4 flows before cut off of the manual system. This will allow for complete training of all involved users.

Currently, efforts are underway to acquire new hardware for experimentation and to develop the necessary software for the use of the VDES in other areas of TPS processing.

Workstand Design

The NASA/UCF research team is presently investigating improvements to the design of workstands used in the OPF. These work stands are used in performing tasks related to the repair and maintenance of the TPS of the Space Shuttle Orbiter vehicles. The overall objectives is to expedite repairs and to improve the accuracy with which these repairs are accomplished.

TPS maintenance is performed after each flight on all external surfaces of each of the orbiter, as well as in the payload bays. However, since most damage to the TPS is sustained on the lower surfaces, particularly in the aft section, the team is restricting its study to maintenance tasks performed from workstands positioned on the OPF floor. Since most of the TPS repair is performed by one or two technicians at a time, the team is limiting the study to design of a two-person workstand. Improvements in the workstands and procedures performed from it are critical to shortening the orbiter process flow since maintenance of the TPS system is often performed after standard maintenance and any required vehicle modifications.

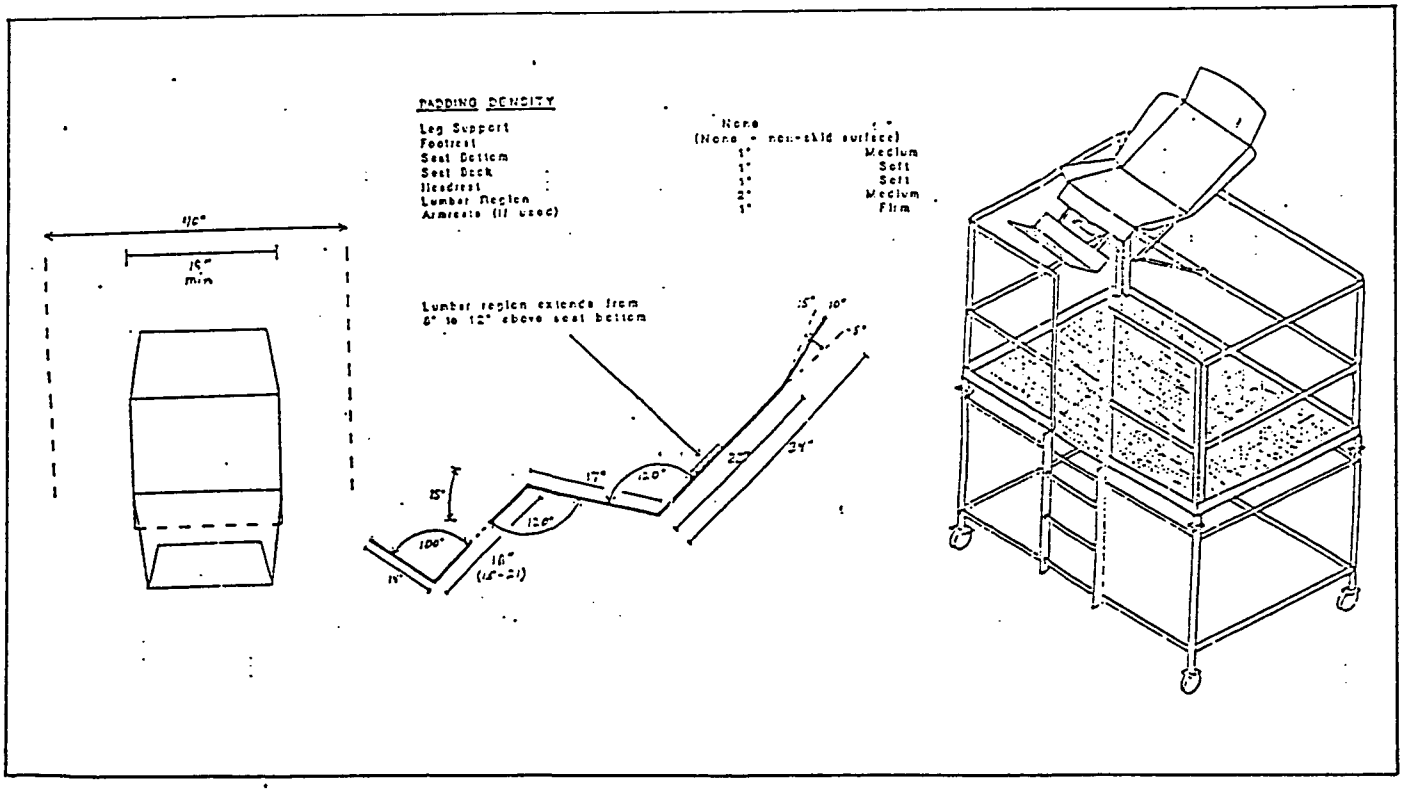

Figure 1. Schematic drawing of mounted seat for overhead operations

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The research team has performed literature and vendor searches, as well as performed an analysis of tasks performed from the two-person workstand. The analysis showed little data exists for work performed in overhead positions. A set of requirements for new designs include: safe access to lower orbiter surfaces in range of 8 to 12 feet above the OPF floor, easy height adjustment and stand movement, rigidity and stability for precise work, ergonomic considerations for unusual postures, and considerations for equipment and paperwork access and storage. Specific requirements for the workstand include continuous height adjustment accomplished from working position, postural support for tasks performed, and compliance with NASA SW -E-0002, NSTS 08242, and MIL-STD-1427C. Three designs are currently being studied by the research team. Figure 1 is a schematic drawing for one of the designs being considered for mounting on existing stands. Other designs consider provisions for special equipment and access to narrow spaces. The research is continuing towards building a prototype of selected design.

Cavity Digitization

The Objective of this research component is to replace the current tile cavity "splashing" process with an integrated, non-contact, 3-D cavity measuring system that directly feeds a numerically controlled machine for tile manufacturing. The first phase of this study is to conduct a technical feasibility study for the elements of such system. Figure 2 is a schematic representing the proposed method for tile replacement. Studying the various techniques shows two promising methods for such applications. Vendor survey

resulted in identifying a limited of possible sources which were contracted. A sample test is being designed to test the validity of the vendor claimed accuracies viz-a-viz design requirements.

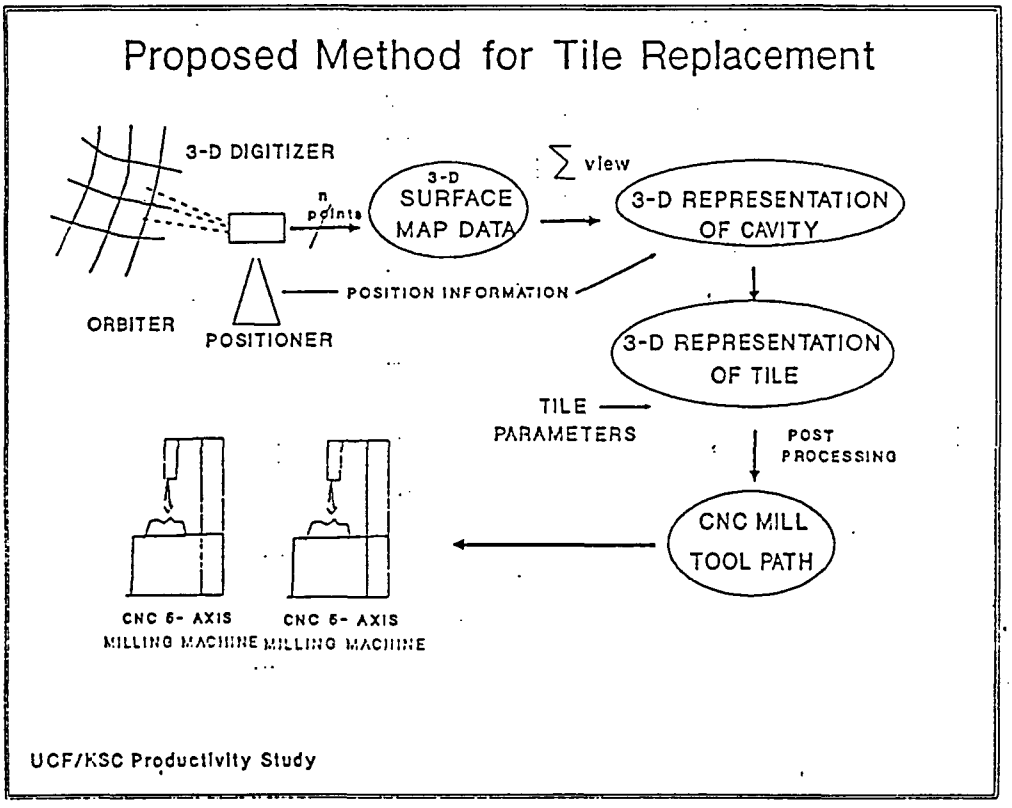

Figure 2. Tile replacement using cavity digitization systems.

In a parallel study aimed at identifying problems associated with on-the-job-orbiter application, a number of problems were identified. These included static and dynamic accuracies, the various positioning requirements for the digitized tool and the difference between digitizing or mapping surfaces vs that of a cavity. Clearly, any adopted technology must be able to also overcome these.

In a related effort, the above problem was formulated as a research proposal and equipment funds were secured from the Florida High Technology and Industry Council for experimentation on a selected technology. A research report was also produced summarizing the findings of the technical study and is available at the UCF library. A number of graduate students are now working on the design of experiments to evaluate and test digitization, and the conversation of the digitization file into a CNC machine instruction for tool guidance as well as resolving the identified problems associated with the application on the shuttle.

Human Performance Productivity

This study was motivated by NASA-KSC's realization that many of the potential strategies to improve orbiter processing productivity would require advanced technologies. These technologies, to be successful, would require acceptance by the current work force. This study focuses on the human factors associated with new technology acceptance by technicians and management associated with the TPS.

In the initial phase of this study, the following specific objectives were set:

- Analyze human performance in TPS processing

- Analyze effects of automation
- Identify areas for performance improvement
- Identify obstacles to performance enhancement and establish a methodology to improve productivity.

Initial study results indicated some problems associated with changes in OR skills requirements, and some resistance to automation and new technologies. In order to help overcome these, there is a need for the establishment of performance standards which eventually would become the basis for performance incentive systems.

Other techniques which the research team is considering involves job enhancement measures, cross training, job rotation, and implementation of participative process strategies. The study is being continued with additional results to be available by the end of Phase 2.

CONCLUSION

The space shuttle concept was originally envisioned as a system which would allow for scheduled trips into earth orbit made economical by the fact that the orbiter as well as its boosters were re-usable. The technology which has made this technically possible dates back to the sixties and seventies. However, the technology which is necessary to make this economically feasible - at least according to original assumptions - only is now beginning to be developed and is the subject of the study described in this paper.

Economic feasibility of the space shuttle is directly linked to the number of missions that can be safely completed during a period of time, and this is directly impacted by the time it takes to process one shuttle from the end of one mission until it is ready for the next. Initial NASA concern, rightly so, was with the technical aspects of the shuttle system - would it perform as was expected? As the answer to this question became positive, NASA eventually began to consider the shuttle an operational system as opposed to an R&D system and had to begin asking itself how it would meet the aggressive launch schedules that had been set. The dramatic and unfortunate Challenger accident immediately shifted the shuttle program back to an R & D mode where the technical issues became the priority. Now that these have apparently been addressed, focus again is being directed to operating the shuttle as a re-usable system whose continued viability will rest, at least partially, on efficiency and economics.

Increasing operational efficiency and productivity has always been the millue of Industrial Engineers in virtually all sectors of the economy. This project represents the initial efforts of bringing the operational efficiency and productivity discipline - Industrial Engineering - into what has here-to-fore been mostly an R&D/Experimental environment. Jointly, NASA, Lockheed, and UCF's Industrial Engineering Department are beginning to develop a relationship which is taking that first small step for them leading to a giant step in productivity for NASA.

Proposals to

Other Funding Agencies

University of Central Florida
Department of Industrial Engineering
College of Engineering
P.O. Box 25000
Orlando, Florida 32816

A

PROPOSAL

TO

HIGH TECHNOLOGY AND INDUSTRY COUNCIL'S

APPLIED RESEARCH GRANTS PROGRAM

FOR

RESEARCH GRANT

Entitled

Photomechanics in the Manufacturing and Repair of Space Shuttle Tile Protection System

August 31, 1989

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A Proposal
submitted to

(Note to SUS DSR.
This is top page of
submitted proposal)

State of Florida
HIGH TECHNOLOGY AND INDUSTRY COUNCIL

APPLIED RESEARCH GRANTS PROGRAM

by

University of Central Florida
College of Engineering
P.O. Box 25000
Orlando, Florida 32816-0450

Title: Photomechanics in the Manufacturing and Repair of Space Shuttle Tile Protection System.

Planning: ____ Operational: X No. of years funded to date: ____

Technology Area: Computer Integrated Engineering and Manufacturing

Principal Investigator(s) Dr. Y.A. Hosni | Dr. W. W. Swart

Name: | |

Signature: | |

Telephone: (407) 281-58117 | (407) 275-2204

Soc. Sec. No. [redacted] | [redacted]

Dept. or Unit Affiliation: UCF | Dept. of Industrial Engr.

Institution (for consortium members): | University of Central Florida

Proposal: New X Renewal ____ 1989-90 Amount Requested: $ 118,169

Executive Summary (100 words): To carry on the research necessary to develop a photomechanics based system for providing three dimensional surface mapping and complete XYZ part measuring device. The idea is to develop a non-contact digitizer (laser based or otherwise) which can rapidly scan complex surfaces, such as cavities in the space orbiter or "product" model and produces XYZ mapping data. The map is then translated via software to a CAD description from which a dye, mold, or tile can be machined.

Endorsements:

	Department Head (or Dept. Center Director)	College Official (or Multi-Dept. Center Director)	University Official
Name	Dr. W. W. Swart	Dr. S. L. Rice	Dr. J. R. Burr
Signature			
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Date			

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1. Introduction:

The Principal Investigators (PIs) of this proposal conducted in Summer 1989, a funded project by NASA-KSC aimed at studying productivity improvement techniques at KSC. Among the findings in this study is the fact that the thermal protection system (TPS) repairs is a significant limiting factor in the shuttle processing at KSC. Present procedures of the tile replacement at KSC involve a splash mold for the cavity, shipping the mold to a company in California, machining the thermal tile using Gunstock Cutter, and returning to KSC for replacement. Among the problems associated with this technique is the lengthy cycle process, the produced tile seldom fit the cavity, and the cost is significantly high. After reviewing alternative methods, a promising technique based on modified Moire interferometry method was found. However Moire technique is known for years as a stress analysis technique, advances in the fields of photomechanics and sterometrics, laser and video technologies, microprocessing, and CAD/CAM makes it feasible to build systems which can perform non-contact scan of complex objects and produce XYZ coordinate data. Such data can be translated to a CAD description from which tool path can be generated and objects such as thermal tiles can be machined with precision*.

The use of such system - if developed - is unlimited in industry. Among the application in manufacturing is the in-process feedback control, CAD/CAM correlation for optimal machining, curvature measurement and gauging, surface finish check and dent detection, mold fabrication and dye manufacturing through prototyping scan. However, the elements of the system are available, integration of these elements in one system as well as resolving problems associated with positioning and precision experimentation remain to be resolved.

This is precisely the objective of this research proposal. It is intended to integrate a system for non-contact surface mapping and XYZ gauging to be interfaced with an NC machine for object production. Experimentation of such system will be in the machining of the thermal tile for the space orbiter.

Because of the impact of this research on the space industry, NASA-KSC funded the feasibility study for this project in Summer 1989 and expressed support in its future development (Section 8). Lockheed Space Operations Company pledged the support of the project manpower, equipment, material as indicated by their supporting letter (Section 8.1), and our estimation of the company's support in Section 6.

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* In a related project being conducted in the Mechanical Engineering Department at UCF, the researchers are investigating the use of laser milling to form the tile. (Hi-tech proposal is being submitted to the Electro-optics and Lightwave Technology Group).

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2. Technical Discussion

2.1. Statement of the problem:

The proposed research work discussed here will solve an important engineering problem. The problem in layman's terms is how to manufacture an object (or part) form its picture automatically. Figure 1 is a schematic of an integrated system in which through the use of a camera or laser directed on a model or prototype, a 3-D descriptive information can be collected, analyzed and translated into machining program which would enable producing the object or the part.

Our vehicle for carrying on the research work will be through the development and experimentation of a photomechanics / or laser digitization system to be used in tile cavity measurement and the manufacturing of tile replacement in the space orbiter at KSC. Figure 2 is a picture of tile formation and cavity replacement. Figure 3 is a typical tile replacement showing critical points required for machining and technical terms used in the following discussion.

The research work will include integration of hardware components in one system, and the development of the necessary software which will resolve problems associated with accuracy, integration, and optimal positioning of the system components, as will as carrying on experimentation of the final system. The ultimate outcome of the research will be a device for digitizing and machining of objects.

2.2. Progress:

The preliminary studies for this project started in the summer 1989. Through a research grant by NASA/KSC, a literature search and technical feasibility study were conducted by the PIs and a graduate student at UCF aiming at finding a better way for space shuttle tile repair and replacement. The study showed that advances in photomechanics, digitization and laser technology makes it feasible to produce the device - the subject of this project. Still remain to be revolved is the optimal selection and modification of the system components as well as its integration and the development of the necessary software to attain the proper accuracy required for machining. A number of companies in Florida for which the outcome of this project may affect were contacted. All pledged support for the project with Lockheed Company committing part of its resources at KSC for the project as well as considering locating a thermal tile manufacturing facility here in Florida. NASA-KSC will support the project in its second year based on the findings of the first year. The PIs is in the process of contacting other Florida Universities for cooperation in the testing of the developed device in their engineering laboratories.

2.3. Method of Attack:

The technical discussion presented here is meant to demonstrate the grasp of the researchers of the technology and the confidence that if this research project materialize, it will result in the introduction of highly promising manufacturing industry in Central Florida. The discussion is based on application of the technology on the manufacturing of thermal tile replacement of shuttle orbiter at KSC, however the technique is equally applicable in the machining of any product.

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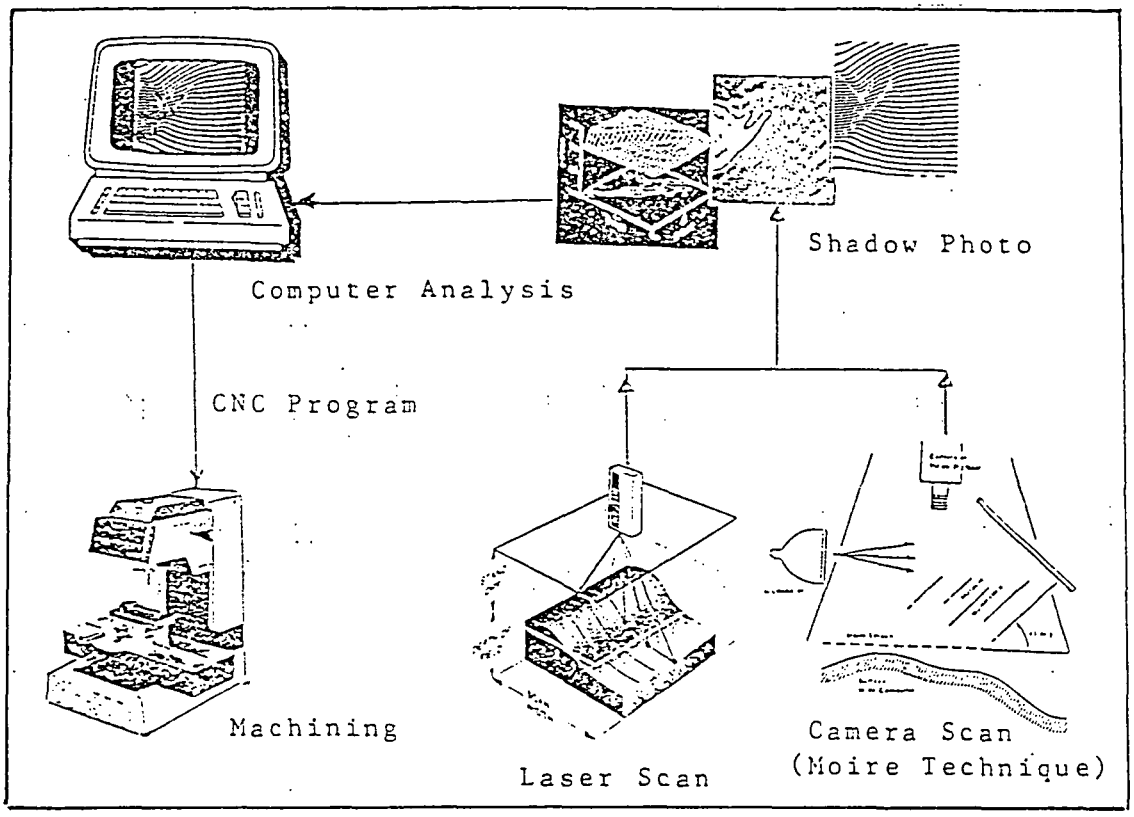

Figure 1. Complete Integrated System

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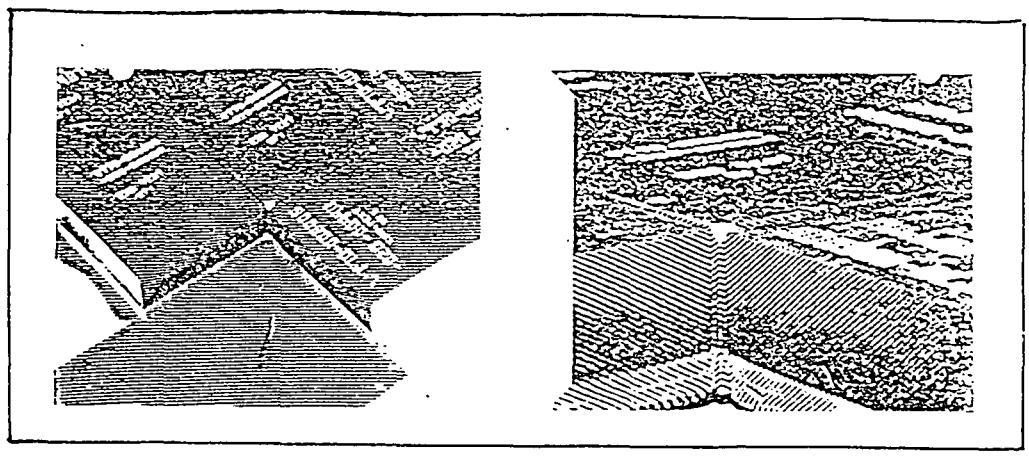

Figure 2. Tile Formation and Cavity Replacement.

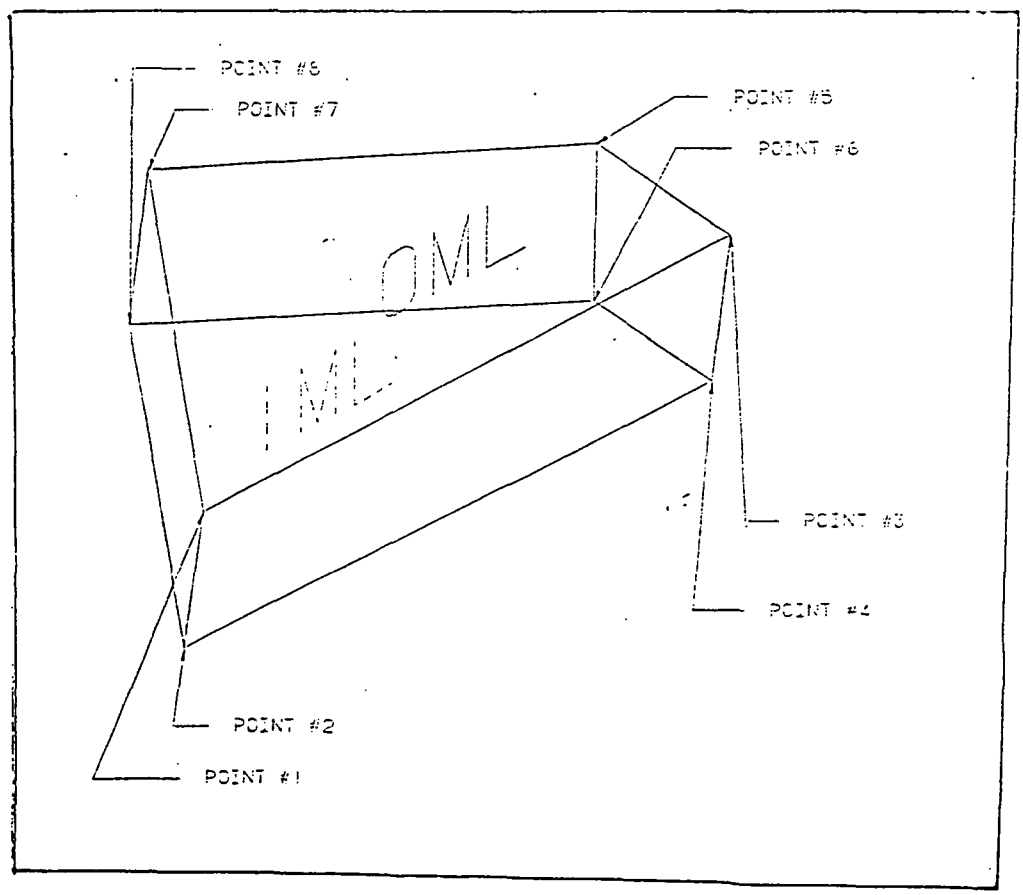

Figure 3. Typical Tile and Critical Points for Machining.

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2.3.1 System Overview

The Photomechanics system proposed for tile cavity measurements will result in a relatively large, 3 ft. x 3 ft., array of equipment containing 3-5 digital video cameras and 4-8 light sources. Figure 4 is the basic system elements. This system will be light-weight enough for one person to lift; however, it will be tripod-mounted for stability and ease of use. Data storage and power supply will be contained within the instrument creating a cordless unit that can be taken anywhere. A PC, complete with frame grabber, image processor, and array processor will be used for data collection and processing as well as system process control. Direct interfacing with a PC-driven NC mini-mill will be locked into and used for development purposes.

The technology selected - laser scanning and/or digitized shadows and projection moire technique - is the least complex solution to this important engineering problem. It was chosen for its simplicity and ease of use and for its ability to be worked into the intricate maze of activities and situations which are common in industrial facilities. This system can be used under the shuttle for areas where the IML curvature is not severe which constitutes nearly 80% of the replacement tiles.

In addition, an estimated savings of $20k per mission would materialize as a result of using the suggested system.

2.3.2 System Breakdown

The actual measurement of a tile cavity can be broken down into four individual measurements:

1. Outer Mold Line (OML) perimeter
2. Wall heights
3. Wall angles
4. Inner Mold Line (IML) contour

Data for each of these dimensions will be collected in rapid succession for photo integration. The total time between the first and last image digitization will be less than a minute. The individual measurements will be made as follows:

1 - OML Perimeter:

The OML perimeter will be determined with lights and camera activated as shown in Figure 5(A). The perimeter of the OML will be obtained directly from digitized images of the tile surface. Using appropriate lighting and Image processing techniques, the computer software will fined the X-Y pixel coordinates of the edges. Software will be written to account for distortion due to perspective and variations in magnification. The perimeter will be broken down into four separate sections with a spline fit to each segment. The splines represent the perimeter of the cavity in real units. Accuracy requirement is approximately 0.005 inches is expected.

2 - Wall height:

The measurement of the height of the tile cavity wall is quite simple. A light is shone at the cavity from a known angle and will cast a shadow onto the IML at the bottom of the

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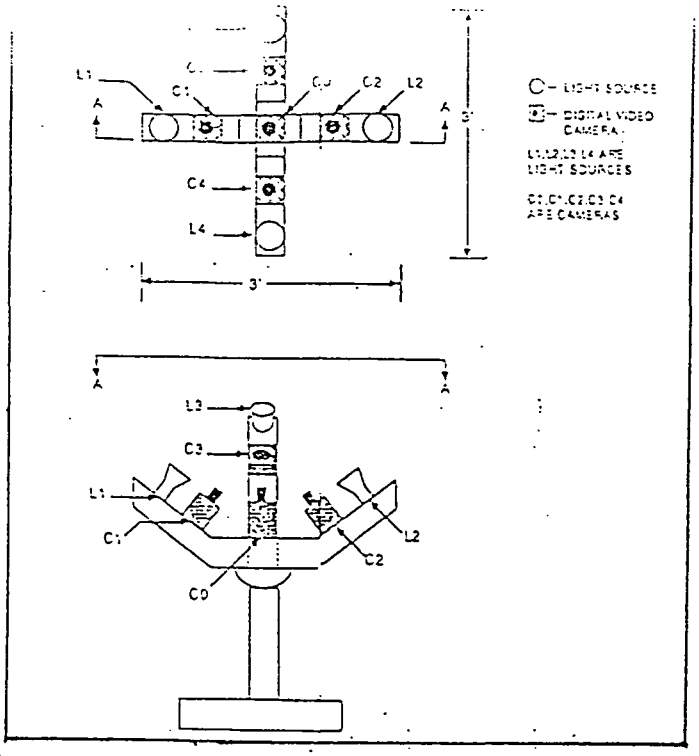
Figure 4. Basic System Elements



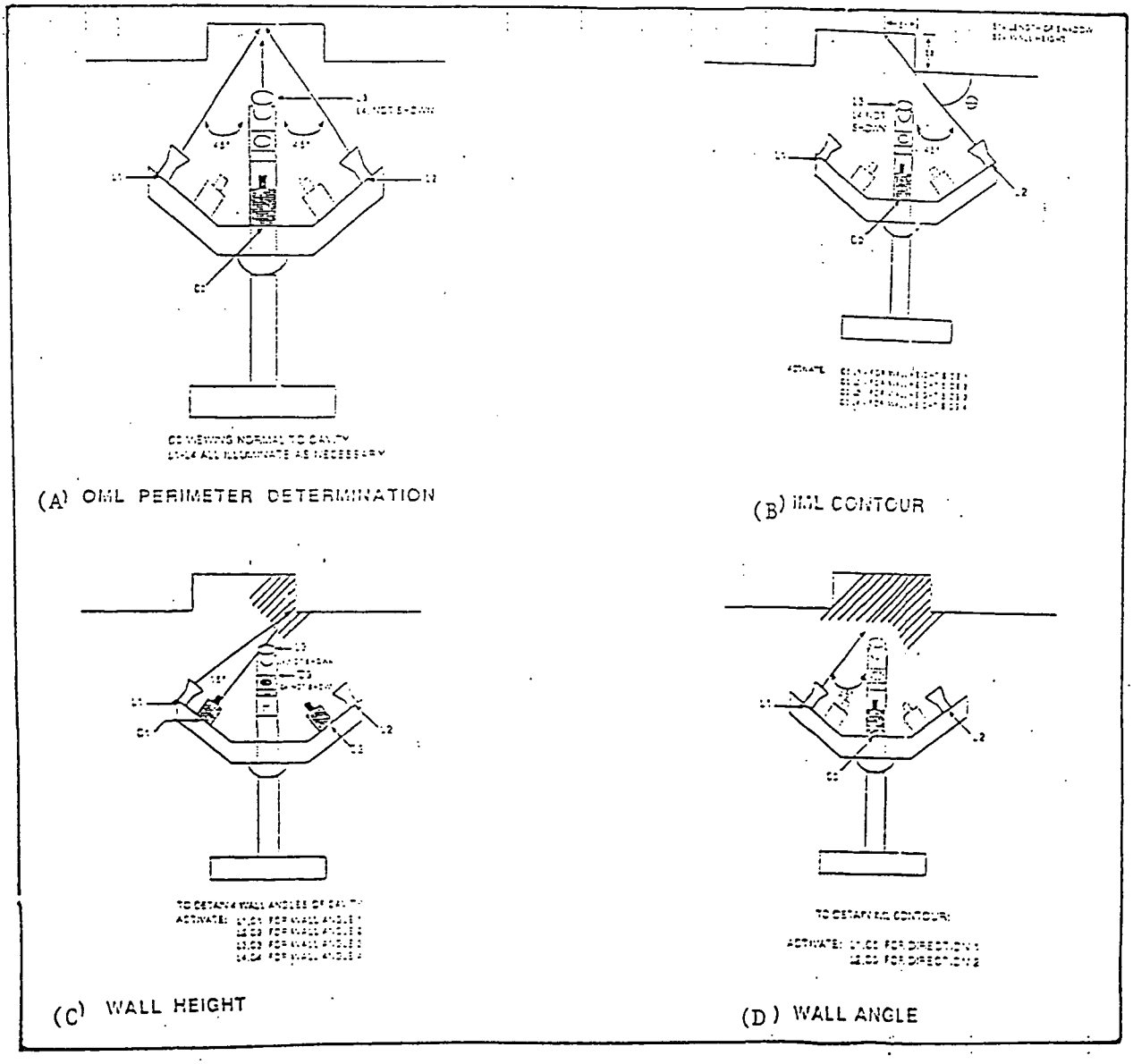


Figure 5. Activation and Positioning of Cameras for Individual Measurements.

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cavity as shown in Figure 5(B). The resulting digitized Image will be used to determine the same image using the proper lighting. Using the width of this shadow and the angle between the instrument head and the shuttle, the wall height will be calculated. Corrections will be made to account for curvature in the IML and the radial that form the edge rims of each shuttle tile. Curvature in the IML can be measured and accounted for directly with a slight loss in accuracy. The radius at the edge rim of a tile can be approximated by suing lights at two distinct angles to make the height measurement. The difference in the height measurements will depend upon the curvature at the edge. It is also possible that an average radius can be found with sufficient accuracy to work for all cavity wall height measurements. This will be at least accurate of the cavity measurements since it depends upon other measurements and certain empirically determined relationships. It is also the least critical of the measurements, having the largest tolerance requirements and easiest fixes for out of spec tile. The software used for this measurement will be the same as that used for the OML perimeter, although the accuracy of this measurement will be worse by a factor of 2 or 3 due to the dependence of the height measurements on the IML contour and on the edge rim radius measurements.

3 - Wall Angle:

The angle the cavity walls form with the IML is the most straight-forward and accurate measurement the system can make. A light source will be used to project a fringe pattern into the corner of the cavity as shown in Figure 5(C). A video camera will be used to record the data from a known relative position. By examining various frequencies, the dominant frequency can be found in the fringe pattern on both the cavity wall and the IML. As long as the orientation of the unit is known, only the ratio of these two frequencies are needed to determine the included angle. The actual pitch of the projected fringe pattern and the magnification of the image is then irrelevant. Software needs to be developed to an accuracy of 0.1 degrees.

4 - IML contour:

The IML will be contoured using projection moire techniques. A fringe pattern will be projected directly onto the shuttle IML and digitized from a known relative position as shown in Figure 5(D). Fringe data can then be processed to yield the surface contour and its orientation. This will then function as the reference frame upon which the individual measurements will be fit together to form a single cavity.

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2.4. Relevance to FHTIC Applied Research Grant Objectives

The State of Florida is embarking on a new era of space technology. The declaration of space port USA in Florida makes it an obligation for the State to advance the state of the technology to that which matches the space technology in support of the expected large number of launching missions. The fact that the contracting company for orbiter preparation - Lockheed - is willing to support this project through committing some of its resources at KSC, and considering moving a tile manufacturing facility from California to Florida underlines the importance of this research. This project has direct impact on other advanced technologies in the field of Computer Integrated Manufacturing (CIM). Any knowledge, findings, and developments resulting from this project will be propagated to all related industries in the State.

The proposed research equipment by its nature is an integration of components currently available as "off-the-shelf," thus the amount of capital invested in equipment is small compared to investment usually required for basic research. The acquisition of this experimental equipment and its housing in the UCF manufacturing laboratories will enable the researchers at UCF to conduct an array of experiments which may go beyond the objectives of this project. It is expected that from two to three graduate students will conduct their graduate studies using the acquired equipment. The technical aspects of the project is multi-engineering discipline, and graduate students trained in the field of photomechanics should graduate as well rounded engineers.

The support of this project is exhibited by the funding by NASA-KSC in Summer 1989 for the preliminary study and by the proposed support by Lockheed Company for future research. NASA-KSC may support the project in its second year.

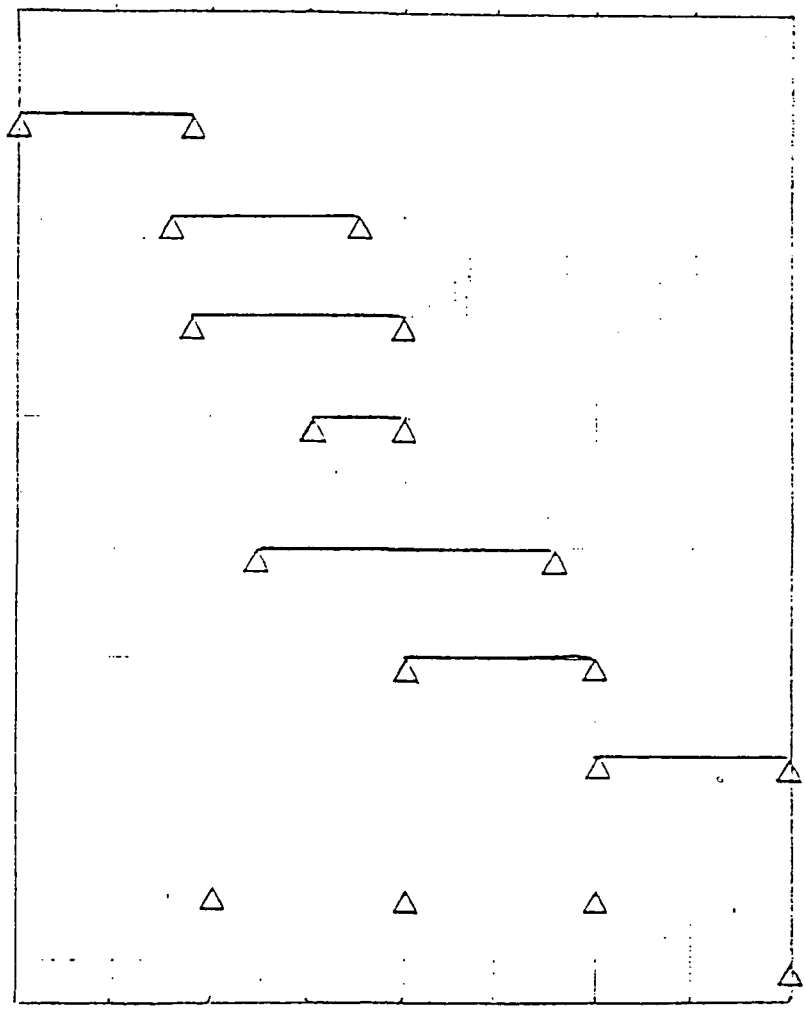
The researchers committed to this project are highly qualified in their field. Their previous work in the preliminary study of this project makes them familiar with the problem and the suggested solution. The work will be complemented by consultation with the Lockheed Photomechanics Laboratory in California on the company's expense.

2.5. Schedule:

The estimated duration of this project is two years. Activities, duration, and expected sequence are listed below. Progress reports summarizing results are to be submitted each six months, with final report including any developed systems due by the end of the second year.

Activity

1. Develpt. of Lab. Tile Cavity Syst.
   - 1.1 System Design
   - 1.2 Component Acquisition
   - 1.3 Software Developt. (Digitiz. & Positioning)
   - 1.4 System experimentation and adaptation
2. Use of System for Machining
   - 2.1 Software Developt. (Image to NC Interface)
   - 2.2 System Integration
   - 2.3 Experimentation for Tile/Product Machining
3. Reporting
   - 3.1 Progress Report
   - 3.2 Final Report



3. Budget

FLORIDA HIGH TECH COUNCIL
APPLIED RESEARCH GRANT PROGRAM
BUDGET FORM

Photomechanics/Shuttle Tile Mfg.

PRINCIPAL INVESTIGATOR/PROGRAM DIRECTOR: Dr. Yasser A Hosni

DETAILED BUDGET FOR 12 MONTH PERIOD				FROM 9/1/95	THROUGH 12/31/99	
PERSONNEL		TIME/EFFORT		DOLLAR AMOUNT REQUESTED		
NAME	POSITION/TITLE	%	Hours per week	SALARY	FRINGE BENEFITS	TOTALS
Dr. Y.A. Hosni	P.I.	25	10	$15,733	$4,102	$19,835
Dr. W. W. Swart	Co-Principal Inv.	15	6	$10,500	$2,737	$13,237
Daniel K. Nasser	Graduate Ass't	50	20	$13,520	$28	$13,548
To be Named	Graduate Ass't	50	20	$13,520	$28	$13,548
			Subtotals	$53,273	$6,896	$60,169
EQUIPMENT – Laser Scanner – Cameras (3) – Microprocessor – Small NC 3-axis machine						$56,000
SUPPLIES						$0
OTHER EXPENSES						$0
TRAVEL						$2,000
CONSULTANT COSTS						
OTHER MISCELLANEOUS COST						
				TOTAL COSTS		$118,169

PRINCIPAL INVESTIGATOR/PROGRAM DIRECTOR: Dr. Y. A. Hosni/Shuttle Tile Mfg.

BUDGET FOR ENTIRE PROJECT PERIOD

order to gain a funding history for this grant, indicate actual budget for each year funded and/or proposed. Also check if "Funded" or "Proposed" for each year (i.e., new proposals will be "Proposed" for all years).

BUDGET CATEGORY TOTALS	1ST BUDGET PERIOD	ADDITIONAL YEARS OF SUPPORT			
		2nd	3rd	4th	5th
PERSONNEL (SALARY AND FRINGE BENEFITS)	$60,169	$60,169			
EQUIPMENT	$56,000	$5,000			
SUPPLIES	$0	$0			
OTHER EXPENSES	$0	$0			
TRAVEL	$2,000	$1,000			
CONSULTANT COST	$0	$0			
OTHER MISCELLANEOUS COSTS	$0	$0			
TOTAL COSTS	$118,169	$66,169			
BUDGET STATUS (check)	___ Funded __X Proposed	___ Funded __X Proposed	___ Funded ___ Proposed	___ Funded ___ Proposed	___ Funded ___ Proposed

TOTAL COSTS FOR ENTIRE PROJECT PERIOD	$ $184,338

BUDGET JUSTIFICATION:

Personnel: The salaries proposed are for 1.4 man-years of effort by the UCF researchers, based on a 40 hour work load. Lockheed Company will provide two researchers for an additional 1.0 man year. The effort by the team will total 2.4 man-years for each year during the life of the project.

Equipment: The estimated cost of the equipment required for conducting the experiments is $95,000. Because some equipment is available in university and research institute laboratories, the cost is reduced to $56,000 in the first year and $5,000 in the second.

Other Expenses: Lockheed Company will commit its VAX Computer at KSC for the software development. The value of this equipment match is $100,000 for the two year duration of the project.

Consultant Cost: Lockheed will also provide consultation from its Photomechanics Laboratory in California valued at $3,000 per year.

4. Personnel:

There will be six researchers involved in this project. Four researchers from UCF, (Hosni, Swart, Nasser, another Graduate Student), and two researchers from Lockheed Company. The responsibility of the project will be that of the PIs (Hosni and Swart).

Dr. Yasser Hosni is a professor in the Industrial Engineering Department at UCF. He has been an active researcher since joining the UCF faculty in 1976. His research interest in the field of productivity enhancement through the use of high technology productivity tools. This include the use of computers and the development of systems for the manufacturing environment. He conducted a number of projects for NASA, NTSC-DOD, the State of Florida, and Florida Production Engineering (FPE). His current project with NASA-KSC deals with productivity enhancement for the Shuttle Thermal Protection System. Among the findings of this project is the feasibility of using the photomechanics technology for Cavity digitization and the thermal tile manufacturing. Dr. Hosni will be the principal investigator for this project . He will be involved in the system design, development of algorithms and its corresponding software, and the design and experimentation of the system. A summary vitae for Dr. Hosni in Section 8.

Dr. William Swart is the Co.PI in this project. He is the Chairman and Professor in the IE Dept. at UCF. He is an active researcher with interest in productivity studies and the use of analytical tools-operation research. Swart and Hosni conducted two successful projects for TPDC and IST, and they are the Co.PIs in the current NASA-KSC productivity enhancement study. Dr. Swart will be involved in the study of optimal positioning of system elements and the extensions of the technology to other applications. A summary vitae for Dr. Swart in Section 8.

The graduate students involved in this project are Mr. Daniel Nasser and another Graduate Student to be named. Mr. Nasser is a Graduate Student with B.S. in electrical engineering and perusing an M.S. in Computer integrated manufacturing in the IE dept.. He is currently involved in NASA-KSC project and he was heavily involved in the feasibility study for the photomechanics digitization of the algorithms necessary for XYZ to NC machine interface, and its corresponding software. Photomechanics in manufacturing will be the topic of his thesis. A vitae for Mr. Nasser is in Section 8.

The search is underway for another graduate student with the proper background to assist in the studying of the accuracy and error correction of the system.

Lockheed Company will provide two researchers -Mr. Scott Study and Mr. Tamim Hamid- each for 50% of his time for the duration of the project. The two researchers are highly qualified in the field of electronic scanning and software development. Their current responsibilities involve the development of voice data entry system for step and gap measurement of the shuttle orbiter. The two researchers will be involved in the Scanning Software development, integration of system in the tile repair process, and resolving problems associated with instrument attachment for the orbiter. Mr. Study will be the liaison between the research team and the Lockheed photomechanics laboratory in California.

5. Other Support Received or Pending:

Dr. Yasser Hosni and Dr. William Swart received a grant for $41,000 for a productivity enhancement study at NASA-KSC. The study involves human engineering, work design, and the introduction of new technologies in the operations at KSC. The duration of this study lasts until November 1989. The study does not include the design or the development of any systems. However, because of the effect of this study on KSC operations, NASA funded the feasibility study for this project as part of the grant.

Both Lockheed and NASA are willing to support and possibly commercialize any development resulting from the study (second year and beyond).

Dr. William Swart received a grant for $100,000 for the study automated housing industry. The study completion date is December 1989. The funded study is not related to this proposal.

6. External Support, Industrial / Federal Collaboration

This proposal can be classified as new collaborative effort between the Lockheed Company, and the University of Central Florida. NASA-KSC funded the technical and economical feasibility study in Summer 1989 as part of a productivity enhancement grant. Also NASA is willing to support the application of any developed system in the future shuttle missions. Proposal will be submitted at that time.

Following are the estimation of dollar amounts received / or pending in support of the study.

Study	Supported by	Amount	Status
- Photomechanics in Support of Tile Processing . (30% of the Prod. Study)	NASA-KSC	$12,300	Funded
- Photomechanics in the Manufact. & repair of TPS * . Manpower (1 M.Y.) $ 40,000 . Computer time $ 100,000 . Consultation $ 6,000 $ 146,000	Lockheed	$146,000 (for two yrs.)	Pending FHTIC

* Manpower is based on $40,000 per M.Y.
Computer Time @ $50k/Yr.
Consultation @ $3k/Yr.

7. Technology Transfer

The progress and the results of this project will be propagated to both the academic and the industrial communities in the State. The researchers of this project will regularly present technical sessions in the annual conference on Productivity through Computer Integrated Engineering and Manufacturing sponsored by FHTIC. On the national level, papers will be presented in the National and International Conference for industrial engineering - the integrated manufacturing systems. The technical findings will be published in the appropriate journals.

It is expected that any developed system will be tested by academicians in the State University System. The results of this research will be exchanged with researchers in the Mechanical Engineering Department at UCF conducting research on laser milling for the thermal tile of the shuttle. A simultaneous effort to the technical research will be the identification of manufacturing companies which will be affected by the photomechanics technology. It is expected that modifications to the system will be required to fit specific appliations. Affected industries will bear any expense in this regard.

8. Additional Supporting Documentation

Following are the additional supporting documents.
Contents are:

- Summary vitae for project researchers
- Supporting letter from Lockheed Space Operations Company
- Supporting letter from NASA-KSC
- Evidence of Summer '89 support by NASA-KSC

YASSER A. HOSNI, Ph.D., P.E.
Professor of Engineering
Department of Industrial Engineering
and Management Systems
University of Central Florida

ACADEMIC BACKGROUND

B.S. Cairo University (Egypt), 1963 (Mechanical Engineering)
M.S. Cairo University (Egypt), 1967 (Production Engineering)
Ph.D. University of Arkansas, 1976 (Industrial Engineering)

EXPERIENCE

Professor, University of Central Florida (1976-present)

Research Scientist, Kuwait Institute for Scientific Research (KISR) (1984-85).

Software Specialist, NCR Company (1970-73)

Chief Production Control, NASR Boilers Co. (1964-73)

Process Engineer, SEMAF Co. (1963-64)

Consulting Experience with such companies as Wackenhut Corporation, Morton Company, and Middle East National Center for Training & Employment, and KISR.

RESEARCH RELATED ACTIVITIES

Principal Investigator for a number of projects, including:

- Energy Management Systems for State Buildings (Florida Energy Office)
- NATO Engagement System Interoperability (NTEC)
- Re-Engineering for the Blind (DOED)
- Regional Resources Constrained Economic Base Model (EIES)
- Microsoftware Development for Industrial Engineering Applications
- TAEG Software Design - Authoring System (NTEC)
- Low Energy Residential Monitoring System (FPSC)
- Knowledge Based Task Analysis System for Space Program Ground Operations (NASA-KSC)
- Task Reliability Model for Space Operations (KISR)
- Manufacturing Productivity (FPE)
- Video-Image Data Base (TPDC)
- Terrain Data Bases for Simulation and Training (IST)
- Productivity Techniques for Thermal Protection System (NASA - KSC)

PROFESSIONAL ORGANIZATIONS AND ACTIVITIES

Member: IIE, IEEE, NSPE, ASEE, SOLE, SME

HONORS AND AWARDS

Alpha Pi Mu
Florida Academy of Sciences
Listed in American Men & Women of Science

PUBLICATIONS/PRESENTATIONS

A number of articles and presentations in the area of Industrial Engineering published or presented in the professional magazines/societies including:

- "Multipurpose Computer System for Plant Layout Design," Computers and Industrial Engineering, International Journal, 2 (No. 1, 1978)
- "Sensitivity Analysis for Multi-Variable Models," Computers and I.E., 3(No. 3), co-authored
- "Indirect Fire Simulators Using Remotely Piloted Helicopter," Naval Training Equipment Center, Interservice/Industry Training Equipment Conference Proceedings, Nov. 1979, Orlando, FL (co-authored)
- Voice Communication with Computers, Computers & IE, Vol. 15, No. 5, 1983
- Desk-Top Logistics Support System, Proceedings, 23 SOLE Symposium, 1988.
- Knowledge-Based Quality Control System, Proceedings of 10th Annual Conference for Computers & IE, 1988.
- Learning Curve Model for Interrupted Production, International Industrial Engineering Conference, 1989.

PRINCIPAL AREAS OF TEACHING AND RESEARCH INTERESTS

Applied Operations Research, System Analysis and Engineering
Software Design, Production Plant Design, and Industrial High Technology Manufacturing Systems.

PROFESSIONAL REGISTRATION

Registered Professional Engineer, State of Florida

WILLIAM W. SWART, Ph.D., P.E.
Chair and Professor
Department of Industrial Engineering
and Management Systems
University of Central Florida

EDUCATION:

Degrees from Clemson University (BSIE) and the Georgia Institute of Technology (M.S.I.E., Ph.D)

TEACHING EXPERIENCE:

Has held professorial ranks at the University of Central Florida, Florida International University, California State University, University of Miami, and the West Virginia College of Graduate Studies.

ACADEMIC ADMINISTRATIVE EXPERIENCE:

Chair of the Industrial Engineering and Management Systems Department (UCF), Director of External Programs (FIU), Associate Dean of the College of Business and Economics (CSU)

INDUSTRIAL EXPERIENCE

Vice President - Management Information Systems, Vice President - Operations Systems, Director - Industrial Engineering and Operations Research, Manager - Operations Research (Burger King Corporation). Operations Research Analyst (E.I. duPont de Nemours). Computer Applications Engineer (International Paper Company).

PROFESSIONAL SERVICE:

President, Space Coast Chapter of IIE (1986, 1987), Member ORSA, TIMS, IIE. Resource Editor, Annals of Tourism Research. Reviewer, Operations Research, Hospitality Management, Annals of Tourism Research.

HONORS AND AWARDS:

TIMS "Management Science Achievement Finalist Award," Restaurant and Institutions Magazine Honorable Mention Award for Food Facilities Design, School Board of Orange County Appreciation Award, Orange Center Elementary School Appreciation Award, Sigma Xi, Alpha Pi Mu, Alpha Iota Delta.

PUBLISHED BOOKS/CHAPTERS/PROCEEDINGS

Author of "Planning for Tourism Development: Quantitative Approaches," and "Integrating Manpower, Personnel, Training, and Safety in Systems Acquisition." Contributor Studies in Linear Programming, Handbook of Operations Research, Productivity Improvement - Corporate Case Studies.

PUBLISHED PROFESSIONAL PAPERS

More than 28 papers in a wide variety of journals and proceedings.

PROFESSIONAL PRESENTATIONS

More than 26 presentations at local, national, and international meetings.

RECENT SPONSORED RESEARCH

Principal Investigator for recent grants totalling in excess of $320,000. Some current projects underway include:

Cost effective, Energy Efficient Industrialized Housing for the Future - Sponsored by the U.S. Department of Energy via the Florida Solar Energy Center.

> This study will define the manufacturing facility, materials, and designs that will constitute tomorrow's housing industry.

A Factory of the Future to manufacture Housing of the Future - Sponsored by General Electric Company.

> This study developed the conceptual design for the Factory of the Future which will utilize G.E. plastic based materials for housing. An actual concept home has been build at G.E. headquarters.

Tile Processing Enhancements - Sponsored by the National Aeronautics and Space Administration (NASA)

> This study seeks to improve the productivity of replacing thermal protection tiles on the space shuttle. Currently, each tile requires in excess of 100 manhours to replace. Each shuttle has 40,000 tiles.

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DANIEL K. NASSER

6546-A San Pedro Square
Winter Park, FL 32792
(407) 679-9397

CAREER OBJECTIVE:

To pursue a professional engineering career with an organization offering opportunity for advancement in management.

EDUCATION:

University of Central Florida, Orlando, Florida
Masters of Science in Computer Integrated Manufacturing
Expected graduation: December 1989

University of Florida, Gainesville, Florida
Bachelor of Science in Electrical Engineering, May 1986
Course emphasis in digital circuits, microcomputer hardware and software.

WORK EXPERIENCE:

Plant Engineer - (1986-1988): Plasticos Santa Cruz C.A.
Caracas, Venezuela
Full time position in plastics film plant. Performed extensive field work in maintenance and upgrading of plant instrumentation and control. Directed group efforts with maintenance crews, quality control personnel, and production supervisors to raise converting efficiency by over 10%. Assisted study and implementation of computerized information system for management.

ACTIVITIES AND INTERESTS:

Fluent in the Spanish Language.
Profficient in the following software: Business BASIC, Pascal, FORTRAN, and assembly languages such as 8085, Z80.
Have working knowledge of general PC based software systems such as Autocad, Lotus 123, Wordperfect etc.
Summer Co-op to machinery manufacturing co. in West Germany.
Won Class of 1982 Mathematics Award.
Hobbies include: boat racing, surfing, and hiking.

References available upon request.

Lockheed Space Operations Company

1100 Lockheed Way
Titusville, Florida 32780

July 19, 1989

Dr. Hosni
University of Central Florida
Orlando, Florida 32816-0112

SUBJECT: FLORIDA HIGH TECHNOLOGY COUNCIL PROPOSAL

Dr. Hosni,

Your proposal to the FHTEC Council concerning photomechanical/laser digitization development for application in manufacturing environments is of immediate interest to Lockheed Space Operations Company at the Kennedy Space Center. Lockheed is striving to reduce Orbiter ground processing timelines to support future mission launch rules. Development of these types of technologies is crucial to achieving these goals.

Photomechanical/laser digitization is of primary interest for Thermal Protection System Cavity Digitization with secondary applications for Payload Bay Door Radiator Inspection and Thermal Protection System Surface Countouring.

Lockheed will support these projects with the necessary resources at our disposal (manpower, hardware, software, access to the Orbiter, etc.). Research and development will take place on flight hardware. Lockheed will provide personnel from Project Management, Thermal Protection Engineering, Structures Engineering, and Tile Operations to support these efforts. In addition, unlimited processing time will be offered on a VAX 8600 mainframe computer.

Successful completion of these projects will result in substantial time savings for the Space Shuttle program. We sincerely look forward to working with the University of Central Florida.

Very truly yours,

LOCKHEED SPACE OPERATIONS COMPANY

K. K. Wagy, Director
Process Technology

Space Administration
John F. Kennedy Space Center
Kennedy Space Center, Florida 32899

NASA

Reply to Attn of: TV-PEO-12/37-89

August 31, 1989

Dr. Yasser A. Hosni
University of Central Florida
Industrial Engineering Department
Orlando, Florida 32816-0112

Subject: Proposal to the Florida High Technology and Industry Council's Applied Research Grants Program

Dr. Hosni,

Your proposal to the Florida High Technology and Industry Council's (FHTIC) 1989-90 Applied Research Grants Program is supported by NASA Vehicle Engineering at Kennedy Space Center. The proposal entitled "Photomechanics in the Manufacturing and Repair of the Space Shuttle Thermal Protection System" describes a technology having the potential to enhance our shuttle processing efforts. Such processing enhancements are of increasing importance as we strive to increase our launch rate.

The Program Integration Section (TV-PEO-12) of Project Engineering will provide project management support and coordinate technical support for your photomechanics research effort. The working relationship established during the Summer 1989 Productivity Improvement Study will continue in support of the FHTIC project.

The successful development of the proposed photomechanics technology will immediately benefit the shuttle program at KSC through tile cavity digitization. Additional applications will be studied as the research period progresses.

James E. McKenzie

James E. McKenzie
Chief, Program Integration Section

cc:
TV-PEO-12/T. Barth
TV-PEO/H. Silipo

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UNIVERSITY OF CENTRAL FLORIDA

DIVISION OF SPONSORED RESEARCH

(407) 275-2671 ORLANDO, FLORIDA 32816-0150 FAX (407) 275-2738

May 9, 1989

Dr. Y. A. Hosni
Dr. W. W. Swart
Dr. S. L. Rice
University of Central Florida
P. O. Box 25000
Orlando, FL 32816

Dear Drs. Hosni, Swart and Rice:

Congratulations on receiving funding in the amount of $36,764 from NASA for your project entitled "NASA - Tile Processing Enhan." I know you are pleased as I am that this support has been provided, and I wish you every success with the study.

Sincerely,

Michael Bass

Michael Bass
Vice President for Research

Attachments

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UNIVERSITY OF CENTRAL FLORIDA

DIVISION OF SPONSORED RESEARCH

(407) 275-2671 ORLANDO, FLORIDA 32816-0150 FAX (407) 275-2738

August 10, 1989

Dr. Y. A. Hosni
Dr. W. W. Swart
Dr. S. L. Rice
Dept. of Industrial Engineering
College of Engineering
University of Central Florida
P. O. Box 25000
Orlando, FL 32816

Dear Drs. Hosni, Swart and Rice:

Congratulations on receiving funding in the amount of $5,000.00 from NASA for your project entitled "NASA - Tile Processing Enhancement." I know you are pleased as I am that this support has been provided, and I wish you every success with the study.

Sincerely,

Michael Bass
Vice President for Research

Attachments

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A PROPOSAL
submitted to

Florida Space Grant Consortium

Program Area: SPACE ASSISTANTSHIP ENHANCEMENT PROGRAM (SAEP)

Faculty PI:

Name: Dr. Yasser A. Hosni

Department/University: Dept. of Industrial Engineering & Mgmt. Sys, U.C.F.

Address: P.O. Box 25000, Orlando, FL 32816

Budget Request:

1. Total Direct Cost	$ 10,000
2. Respondent = NASA Matching Obligation (0.5851 * Line 1)	$ 5,640 required. Actual= $6,000
3. NASA Direct Cost Obligation (0.4149 * Line 1)	$ 4,000
4. NASA Overhead Obligation (0.1701 * Line 1)	$ 1,640

Beginning Date: 5-8-90 Ending Date: 9-1-90

(Signature) Faculty P.I.	(Signature) Department Head
Dr. Yasser Hosni Name:	Dr. William Swart Name:
Professor Title:	Chair, Dept of IEMS Title:
Feb. 21, 1990 Date:	Feb. 21, 1990 Date:
(Signature) College Official	(Signature) University Official
Dr. Gary E. Whitehouse Name:	Dr. Joan R. Burr Name:
Dean, College of Engineering Title:	Director of Sponsored Research Title:
Feb. 21, 1990 Date:	Feb. 21, 1990 Date:

The University certifies that the SAEP funds, including the matching funds, will not supplant funds intended for the recipient research program, that all funds will be translated into increased programmatic support.

UNIVERSITY OF CENTRAL FLORIDA
Engineering and Industrial Experiment Station
College of Engineering
P.O. Box 25000
Orlando, FL 32816

A

PROPOSAL

TO THE

FLORIDA SPACE GRANT CONSORTIUM

(Space Assistanship Enhancement Program)

entitled

Risk Assessment of Ground Operations for Space Missions

February 19, 1990

Dr. Yasser A. Hosni
Professor
Dept. of Industrial Engineering
and Management Systems
Ph: (407) 281-5817

Dr. William Swart
Chair
Dept. of Industrial Engineering
and Management Systems
Ph: (407) 281-5306

Dr. Gary E. Whitehouse
Dean
College of Engineering
Ph: (407) 275-2156

Dr. Joan R. Burr
Director
Division of Sponsored Research
Ph: (407) 275-2671

Risk Assessment of Ground Operations for Space Missions

Introduction:

The space shuttle concept was originally envisioned as a system which would allow for scheduled trips into earth orbit made economical by the fact that the orbiter as well as its boosters were re-usable. The technology which has made this technically possible dates back to the sixties and seventies. However, the technology which is necessary to make this economically feasible is now beginning to be developed and is the subject of this study.

Economic feasibility of the space shuttle is directly linked to the number of missions that can be safely completed during a period of time, and is directly impacted by the time it takes to process one shuttle from the end of one mission until it is ready for the next. Initial NASA concern, rightly so, was with the technical aspects of the shuttle system--would it perform as expected? As the answer to this question became positive, NASA eventually began to consider the shuttle an operational system as opposed to an R & D system and had to begin asking itself how it would meet the aggressive launch schedules that had been set.

In a pilot project conducted by UCF and NASA-KSC aimed at identifying potential problems associated with ground operations at KSC, scheduling of tasks and measuring the risk of operation interruptions were identified.

The overall purpose of this study is to develop methodology that will enable managers and decision makers to assess the vulnerability, or risks, of a proposed launch to events that lead to mission interruption, to identify the major contributors to these risks, and to make recommendations as to the management, engineering, and operations analyses that are needed to reduce these risks.

While this study involves the development of a large computer package to handle the expected large amount of data, and the computation associated with the methodology algorithms; a front end program is needed to pre-process the data and identify its nature. Data will be solicited from experts as well as experiences gained from previous missions. The development of this program is the subject of this proposal.

Objectives:

The objective of this component of the study is to develop a computer program to identify the statistical distribution of task duration required between space missions.

The program will interface with a much larger simulation based package aimed at assessing the risk associated with computing ground operations for a mission. Risk will be assessed for various schedules and scenarios.

Personnel:

It is estimated that this study will be completed in one semester (4 months). A graduate student, Mr. Xia Lu, will work under the supervision of Dr. Yasser A. Hosni of the Department of Industrial Engineering (IE) at UCF. Dr. Hosni is the Principal Investigator for a productivity study currently being conducted at NASA-KSC.

The student, Mr. Xia Lu, is currently pursuing his MSE in the IE department. His background is compatible with this study. He developed a seed program in the form of an expert system for Distribution Analysis as part of his class project in a related course. The study here will be part of his research thesis in the Master's program.

Budget:

1. Salaries:

1.1. Dr. Y. Hosni (20% SU; 10% 3 weeks in Fall	$4,480	
1.2. Graduate student (20 hrs./week for 16 weeks @ 12.5/hr.)		$ 4,000

2. Expenses:

2.1. Computer time	1,200	
2.2. Transportation	320	
UCF MATCH TOTAL= $6,000		
Total required from Florida Space Grant Consortium		$4,000

P.S. Items 1.1, 2.1, 2.2 will be covered by the IEMS department at UCF.

National Aeronautics and
Space Administration

John F. Kennedy Space Center
Kennedy Space Center, Florida 32899

NASA

y to Attn of

TV-PEO-12

February 22, 1990

Dr. Yasser A. Hosni
Industrial Engineering and
Management Systems
University of Central Florida
Orlando, FL 32816

Dr. Hosni:

The purpose of this letter is to express support for your proposal to the Florida Space Grant Consortium entitled "Risk Assessment of Ground Operations for Space Missions."

NASA/Kennedy Space Center is currently involved in a major project to improve the efficiency and effectiveness of the planning and scheduling of shuttle processing activities. The risk assessment program described in your proposal would significantly enhance this effort.

I look forward to working with you on this endeavor.

Tim Barth

Tim Barth

cc:
TV-PEO/H. Silipo
TV-PEO/J. E. McKenzie
TV-PEO-1/G. Thurston
TV-PEO-12/R. Bates

YASSER A. HOSNI, Ph.D., P.E.
Professor of Engineering
Department of Industrial Engineering
and Management Systems
University of Central Florida

ACADEMIC BACKGROUND

B.S. Cairo University (Egypt), 1963 (Mechanical Engineering)
M.S. Cairo University (Egypt), 1967 (Production Engineering)
Ph.D. University of Arkansas, 1976 (Industrial Engineering)

EXPERIENCE

Professor, University of Central Florida (1976-present)
Research Scientist, Kuwait Institute for Scientific Research (KISR) (1984-85).
Software Specialist, NCR Company (1970-73)
Chief Production Control, NASR Boilers Co. (1964-73)
Process Engineer, SEMAF Co. (1963-64)
Consulting Experience with such companies as Wackenhut Corporation, Morton Company, and Middle East National Center for Training & Employment, and KISR.

RESEARCH RELATED ACTIVITIES

Principal Investigator for a number of projects, including:

- Energy Management Systems for State Buildings (Florida Energy Office)
- NATO Engagement System Interoperability (NTEC)
- Re-Engineering for the Blind (DOED)
- Regional Resources Constrained Economic Base Model (EIES)
- Microsoftware Development for Industrial Engineering Applications
- TAEG Software Design - Authoring System (NTEC)
- Low Energy Residential Monitoring System (FPSC)
- Knowledge Based Task Analysis System for Space Program Ground Operations (NASA-KSC)
- Task Reliability Model for Space Operations (KISR)
- Manufacturing Productivity (FPE)
- Video-Image Data Base (TPDC)
- Terrain Data Bases for Simulation and Training (IST)
- Productivity Techniques for Thermal Protection System (NASA - KSC)

PROFESSIONAL ORGANIZATIONS AND ACTIVITIES

Member: IIE, IEEE, NSPE, ASEE, SOLE, SME

HONORS AND AWARDS

Alpha Pi Mu
Florida Academy of Sciences
Listed in American Men & Women of Science

PUBLICATIONS/PRESENTATIONS

A number of articles and presentations in the area of Industrial Engineering published or presented in the professional magazines/societies including:

- "Multipurpose Computer System for Plant Layout Design," Computers and Industrial Engineering, International Journal, 2 (No. 1, 1978)
- "Sensitivity Analysis for Multi-Variable Models," Computers and I.E., 3(No. 3), co-authored
- "Indirect Fire Simulators Using Remotely Piloted Helicopter," Naval Training Equipment Center, Interservice/Industry Training Equipment Conference Proceedings, Nov. 1979, Orlando, FL (co-authored)
- Voice Communication with Computers, Computers & IE, Vol. 15, No. 5, 1983
- Desk-Top Logistics Support System, Proceedings, 23 SOLE Symposium, 1988.
- Knowledge-Based Quality Control System, Proceedings of 10th Annual Conference for Computers & IE, 1988.
- Learning Curve Model for Interrupted Production, International Industrial Engineering Conference, 1989.

PRINCIPAL AREAS OF TEACHING AND RESEARCH INTERESTS

Applied Operations Research, System Analysis and Engineering

Software Design, Production Plant Design, and Industrial High Technology Manufacturing Systems.

PROFESSIONAL REGISTRATION

Registered Professional Engineer, State of Florida

Project Outcome Presentations

UNIVERSITY OF CENTRAL FLORIDA
INDUSTRIAL ENGINEERING PROJECT

PRODUCTIVITY IMPROVEMENT TECHNIQUES

C-6

Project Outcome

Presentation to NASA/KSC

Project Categories

* RESEARCH PROJECT CONSISTS OF 4 COMPONENTS

  - THE CAVITY DIGITIZATION (Dan Nasser/Labiche Ferreira/ Jueng shing Hwang)
  - VOICE DATA ENTRY TRAINING (John Scarboro/ /Hamim Hamid/Ken Cole)
  - WORKSTAND DESIGN (JOhn Creech/Lisa Guthrie)
  - HUMAN PERFORMANCE ENHANCEMENT (John Creech)

* RESEARCHERS FROM ALL ACADEMIC LEVELS WITHIN THE I DEPARTMENT ARE INVOLVED
  - 3 FACULTY MEMBERS (Hosni, Swart, Lee)
  - 7 GRADUATE STUDENTS (M.S. and PhD)
  - 2 UNDERGRADUATES (SENIOR CLASS PROJECT) (Jim Brice & S. Berkowitz)

UCF/KSC

BACKGROUND

- THE ADVANCED PROJECTS, TECHNOLOGY, AND COMMERCIALIZATION OFFICE (PT) DEVELOPED A COOPERATIVE RESEARCH AGREEMENT WITH THE UNIVERSITY OF CENTRAL FLORIDA CONSISTING OF SEVEN RESEARCH PROJECTS

- "PRODUCTIVITY IMPROVEMENT TECHNIQUES" IS THE INDUSTRIAL ENGINEERING RESEARCH PROJECT

  - THE OBJECTIVE OF THE RESEARCH IS TO IMPROVE SHUTTLE PROCESSING EFFICIENCY AND EFFECTIVENESS WITH INDUSTRIAL ENGINEERING APPLICATIONS

  - CURRENT RESEARCH IS FOCUSED IN THERMAL PROTECTION SYSTEM (TPS) PROCESSING

- A 'SUMMER' 1989 (MAY - NOVEMBER) RESEARCH AGREEMENT IS THE PILOT FOR ESTABLISHING A 3-YEAR GRANT PROGRAM

  - THE 3-YEAR PROPOSAL WAS PREPARED BY UCF AND TV, APPROVED BY PT, AND IS CURRENTLY UNDER COST AND TECHNICAL EVALUATION IN THE PROCUREMENT OFFICE

- PRIMARY CONTACTS:

  - DR. BILL SWART (UCF INDUSTRIAL ENGINEERING DEPARTMENT CHAIRMAN)
  - DR. YASSER HOSNI (UCF PRINCIPAL INVESTIGATOR)
  - TOM DAVIS (PT-AST)
  - WARREN CAMP (PT-PAS)
  - CEDRIC HILL (TV-MSD-11)
  - TIM BARTH (TV-PEO-12)
  - TAMIM HAMID

UNIVERSITY OF CENTRAL FLORIDA
INDUSTRIAL ENGINEERING PROJECT

TILE CAVITY DIGITIZATION IN SUPPORT OF TILE PROCESSING

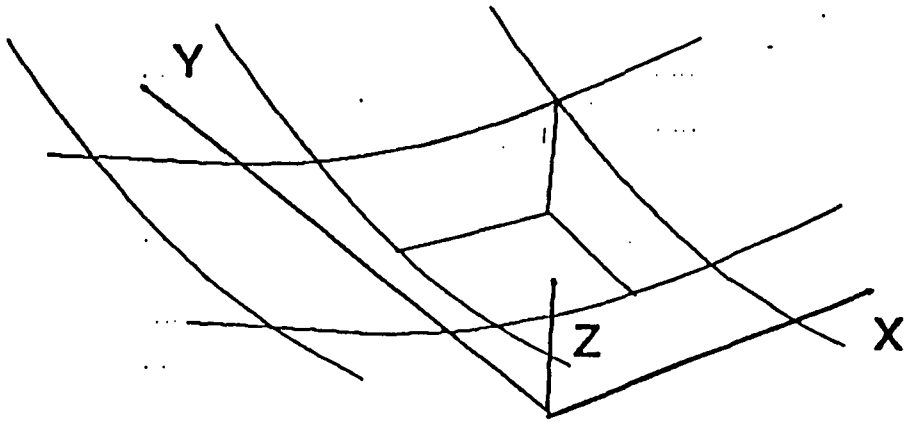
(Technical Feasibility Study)

UCF/KSC Productivity Study

- Background
- Objectives
- Procedure
- Partial Outcome

Background
TILE CAVITY DIGITIZATION

* Map out a surface area on the tile structure that includes a cavity (X-Y)



* Obtain a depth measurement (Z) for every point on this area
* Resulting data represents tile cavity contour where machining information can be obtained through the use of CAD/ CAM to CNC

Background

JUSTIFICATION

* Cost of manpower for tile replacement is high (approximately $ 800.00 per tile)

* New technologies in 3-D measurement offer potential savings by automating tile replacement functions

* Current efforts at KSC involve the implementation of CAD/CAM. Automating the generation of tile design data by digitization will lead to a highly efficient system

Potential Cost Savings for Tile Replacement
Per Mission Cost *

CAVITY SPLASH
& REWORK 30 HOURS/TILE * 25 TILES/MISSION $20,632.52

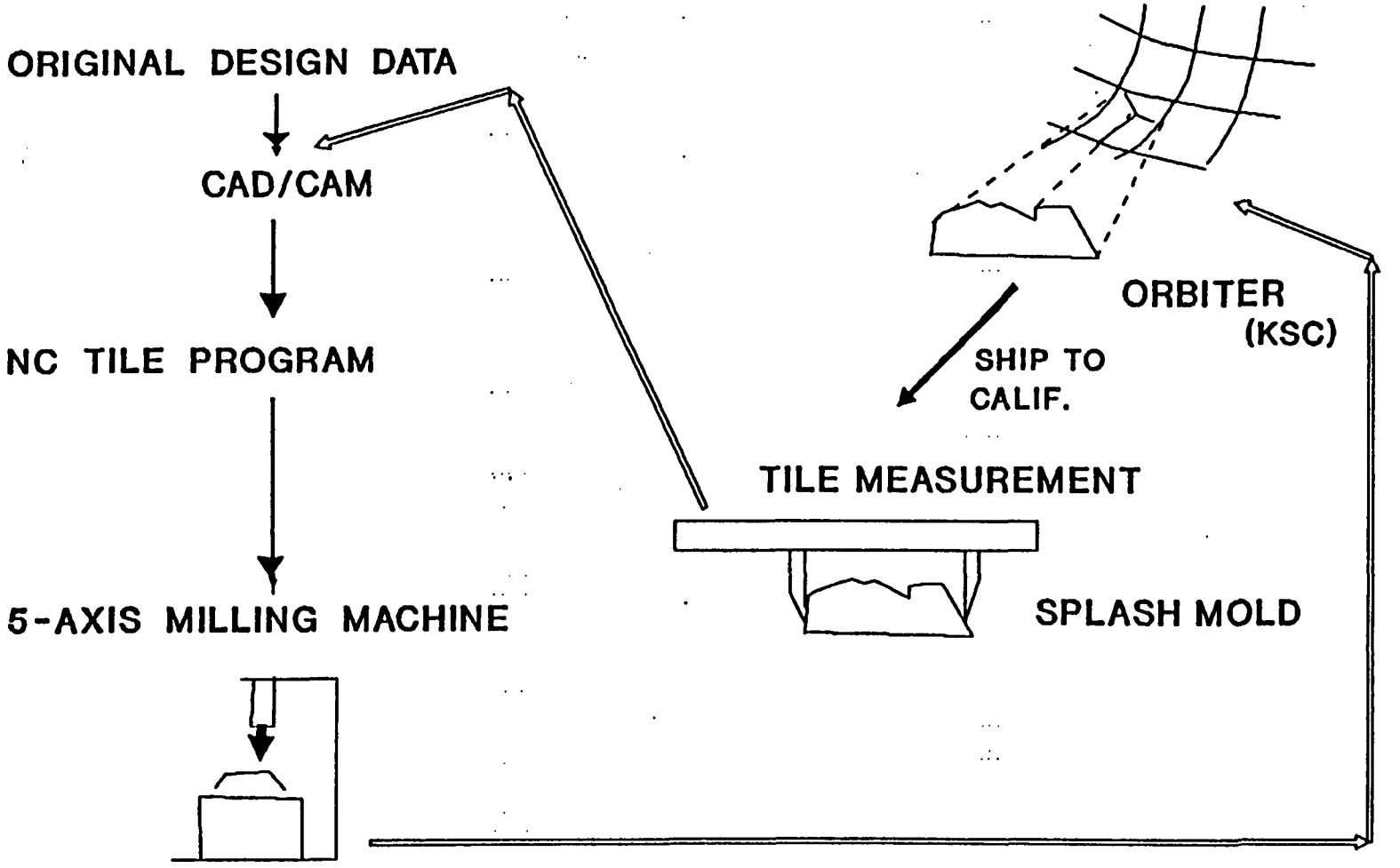
(Approximately 75% of tiles need rework)

DIGITIZATION
3 HOURS/TILE * 25 TILES/MISSION $2,847.00

* Data obtained by previous studies

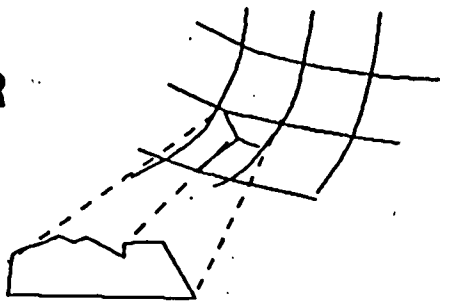
Background

Current Methods for Tile Fabrication



Potential Errors in Current Method for Tile Replacement

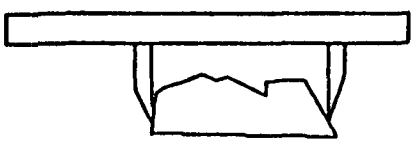
1) MOLDING ERROR



ORBITER
(KSC)

2) MEASUREMENT ERROR

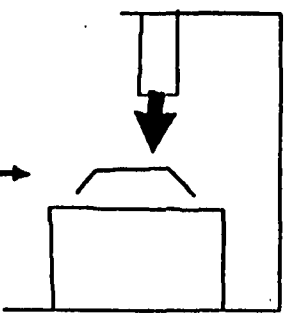
TILE MEASUREMENT



SPLASH MOLD

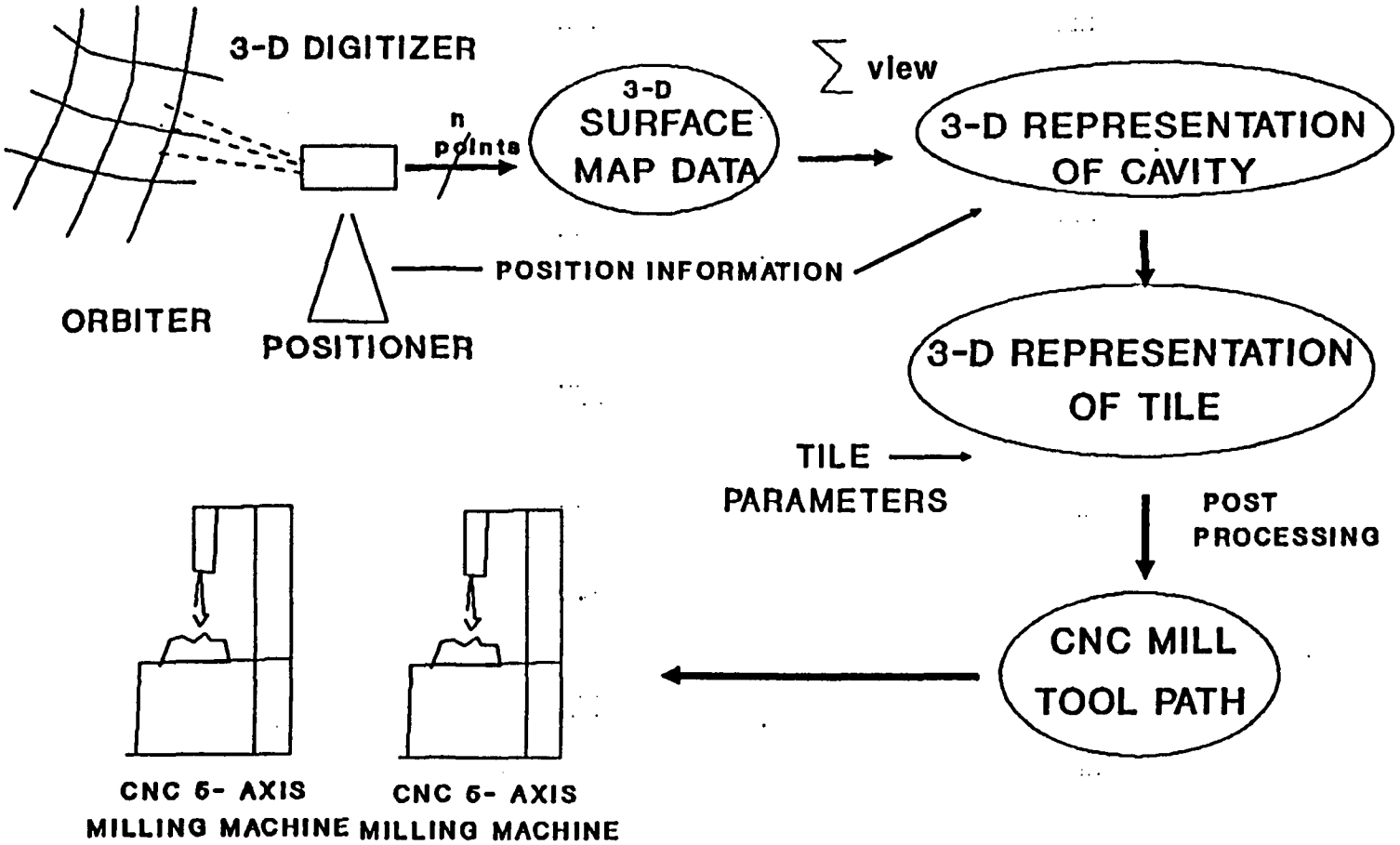
CAD/CAM

3) MACHINING ERROR



UCF/KSC Productivity Study

Proposed Method for Tile Replacement



UCF/KSC Productivity Study

Objectives

* OVERALL
  - Replace the tile cavity "splashing" process with an integrated, non-contact, 3-D cavity measuring system that directly feeds a numerically controlled mill for tile manufacture
    - Technical feasibility study
    - Economic feasibility study
* SPECIFIC
  - Research the state of the art in 3-D digitization
  - Identify and resolve problems associated with orbiter cavity digitization
  - Study available equipment
  - Identify criteria for system evaluation
  - Gain knowledge in 3-D measurement applications
  - Complete research report
  - Submit Florida High Technology and Industry Council (FHTIC) proposal for further studies

Procedure

1. Research the state of the art in 3-D digitization
   - Literature search (STAC, technical papers, trade publications, etc.)
   - Knowledge acquisition (Lockheed, NASA, UCF, CREOL NIST, Univ. of Cincinatti; vendors, texts)

2. Perform equipment availability study (vendor search through industry directories, trade periodicals, vendor interaction)

3. Identify problems associated with orbiter cavity digitization
   - Evaluate limitations of digitizing systems
   - Evaluate problems caused by the unique characteristics of KSC processing environment

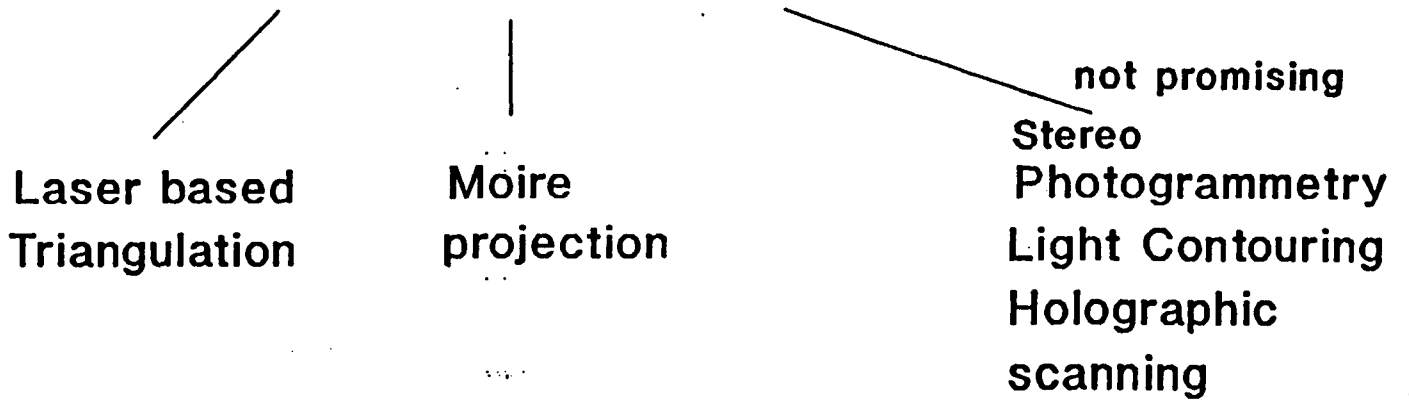
4. Identify criteria for system evaluation
   - Careful study of the digitization process

Sources of Information

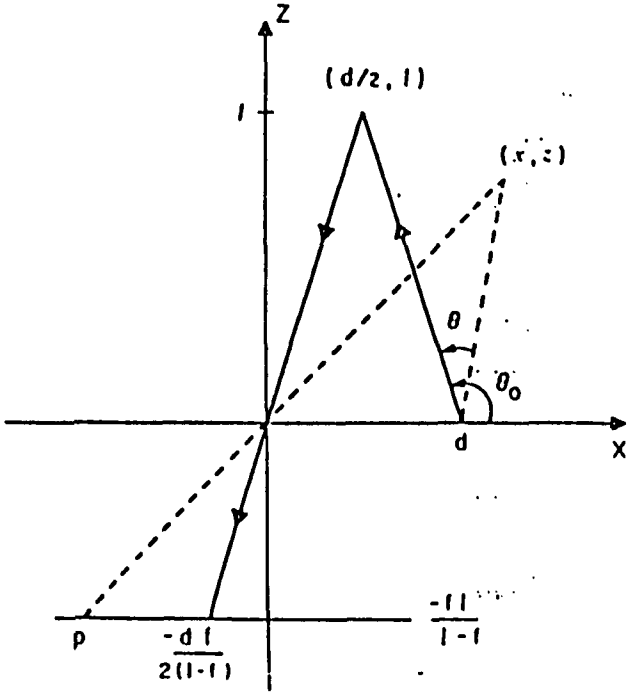
- UNIVERSITY OF CENTRAL FLORIDA (UCF)
- CENTER FOR RESEARCH in ELECTRO-OPTICS and LASERS (CREOL)
- LOCKHEED
- NASA
- NIST (NATIONAL INSTITUTE FOR STANDARDS AND TECHNOLOGY)
- UNIVERSITY RESEARCH
- SOUTHERN TECHNOLOGICAL APPLICATIONS CENTER (STAC)
- VENDORS
- TRADE PERIODICALS
- INDUSTRY DIRECTORIES

Outcome

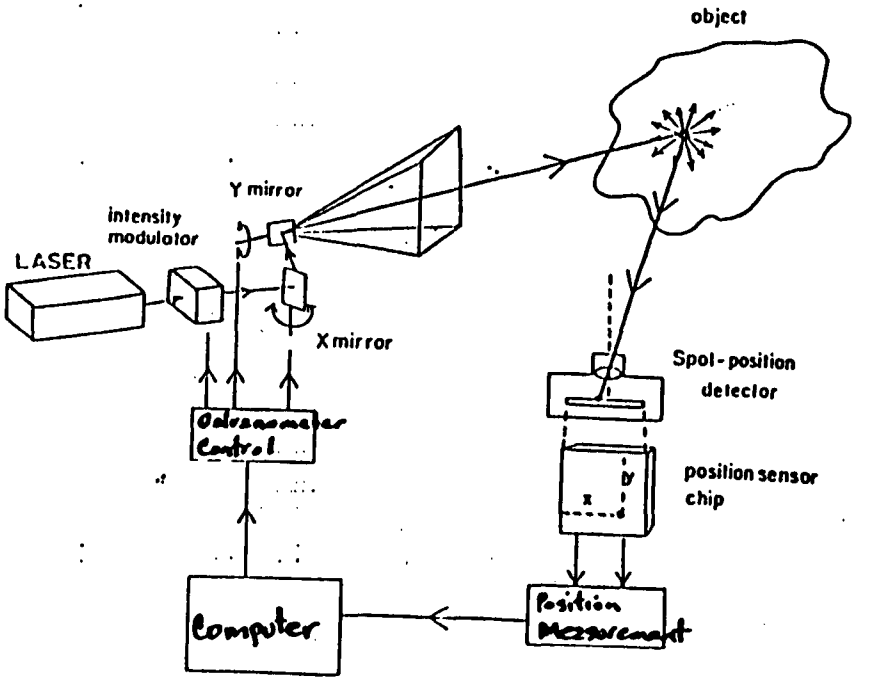
1. State of the art in 3-D digitization

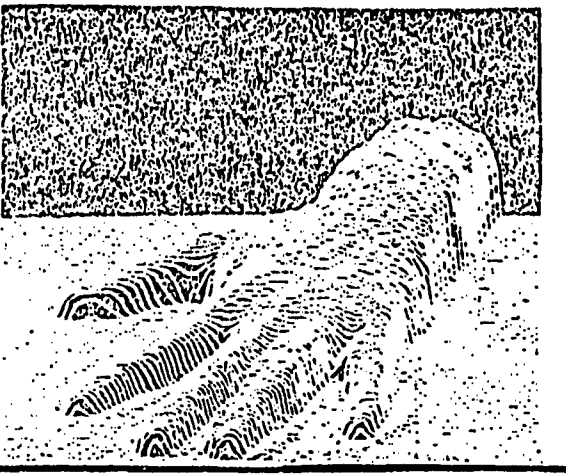


LASER BASED TRIANGULATION



Conventional triangulation geometry.





UCF/KSC Productivity Study

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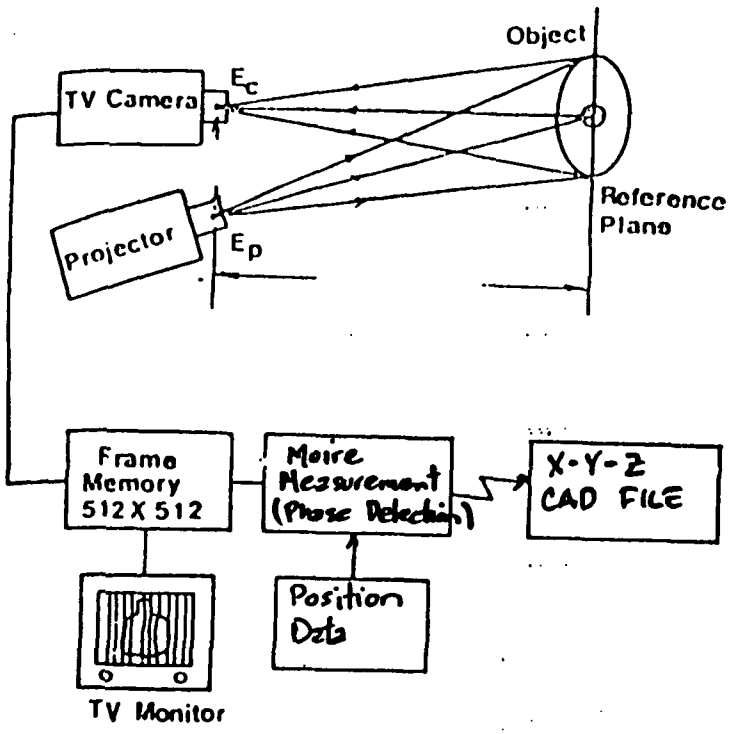
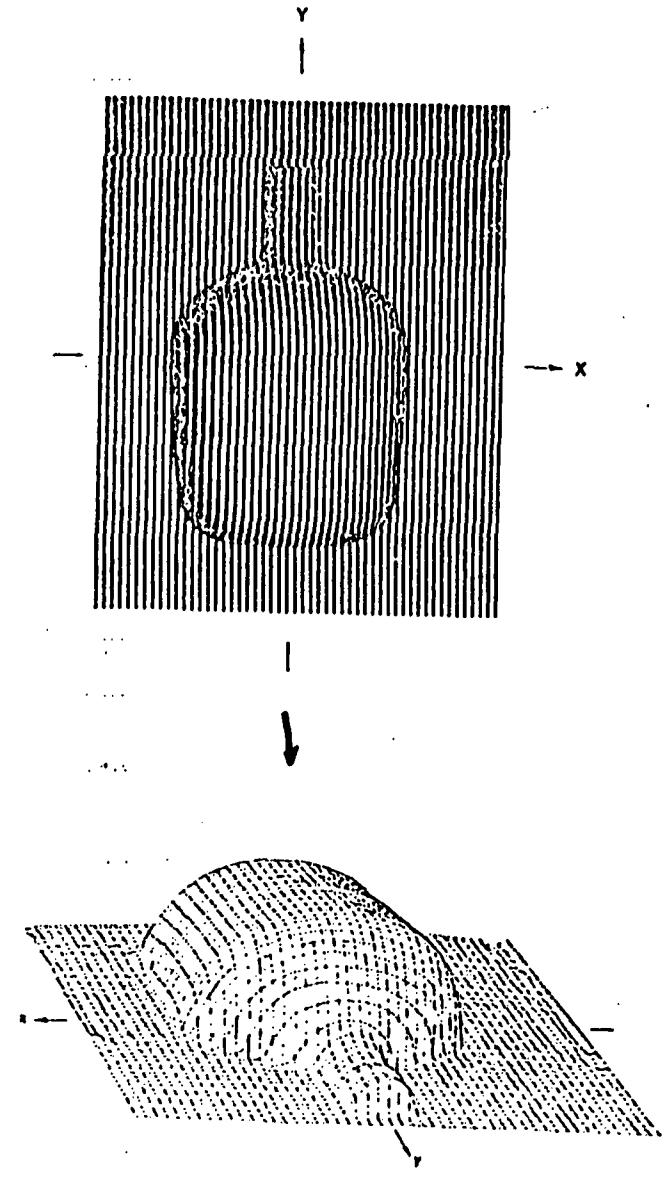
MOIRE PROJECTION BASED SYSTEMS





UCF/KSC Productivity study

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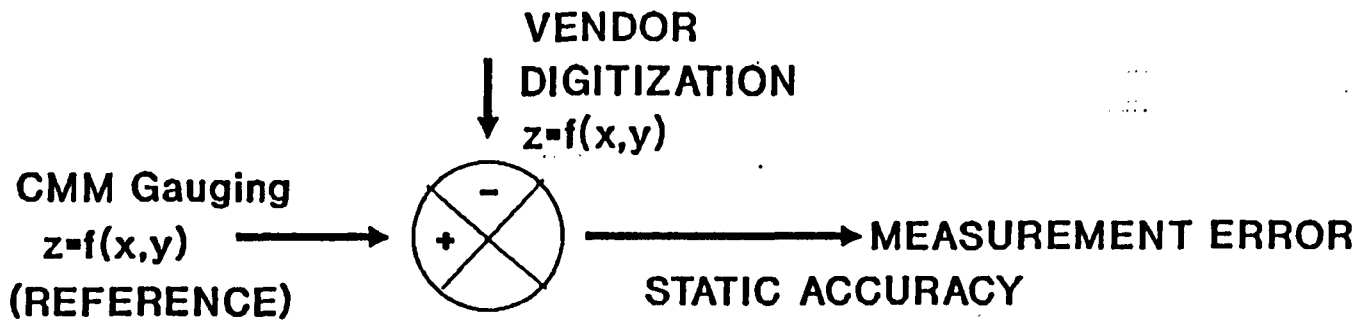
Outcome
(cont)

- 2. PROBLEMS ASSOCIATED WITH ORBITER CAVITY DIGITIZATION
  - Static accuracy
  - Dynamic accuracy
  - Physical system requirements
  - Ease of use & user transparency
  - Viewing
  - Positioning alternatives
  - Cost
  - Solid surface mapping vs. cavity digitization
  - System reliability

Problems Associated with Cavity Digitization

* Static Accuracy : Measurement error inherent to the digitizer.

  - Perform vendor digitization test to verify stated claims of accuracy.
    1. Send sample tile section with cavity to vendors and obtain X-Y-Z values.
    2. Compare with CMM gauging of same section.



Problems Associated with Cavity Digitization (cont.)

* Dynamic Accuracy : Measurement error due to changes between cavity and digitizer coordinates during cavity digitization.
  - Obtain data on shuttle coordinate changes (oscillation)
  - Assure a stable positioning system for the digitizer.
  - Investigate the possibility of movement (oscillation) elimination
* Physical Requirements : Consider factors of digitizers and positioners such as weight, standoff, reflectivity, compactness, etc.that will affect efficient cavity digitization.

Problems Associated with Cavity Digitization (cont.)

* Ease of use : Consider total effort involved in producing a CNC part program from cavity digitization.
  - Digitization procedures
  - Tile design data input
  - Generation of CNC code from 3D file

* Positioning : Design a positioning system that allows for complete and accurate views of the tile cavity.
  - Standoff considerations
  - Angle of reflection considerations

Vendor Survey

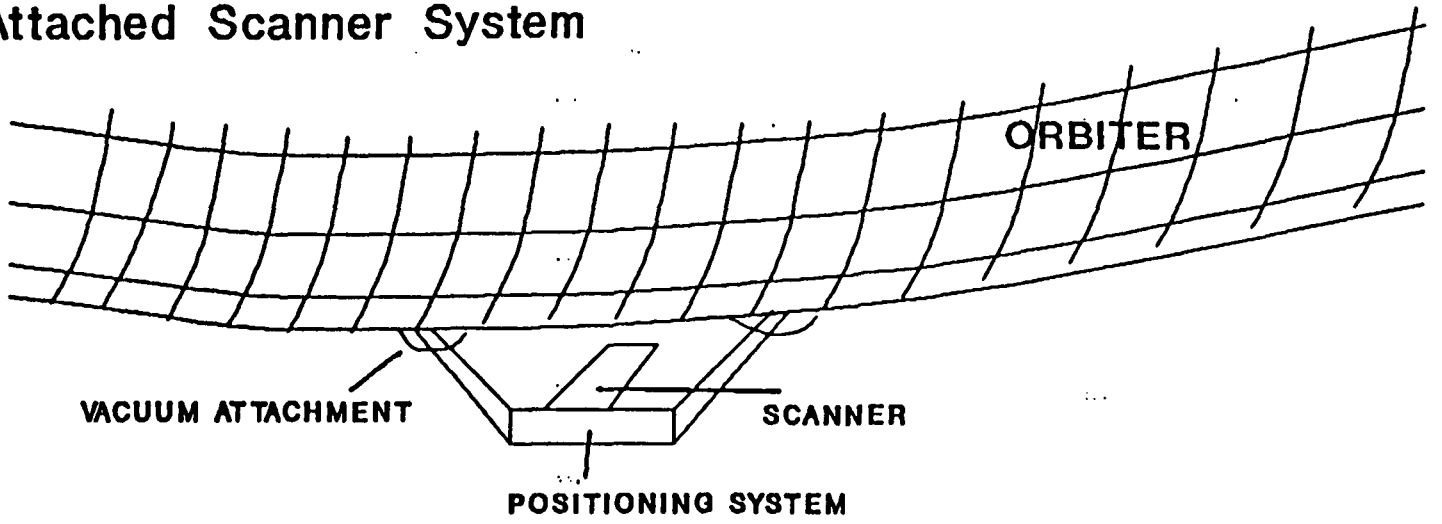
COMPANY NAME	PRODUCT MODEL	OPERATION	STATED ACCURACY	APPROXIMATE COST
HYMARC	HYSCAN 45-C	LASER TRIANGULATION	0.001"	$95K + POSITIONING
EOIS	MK VII	MOIRE PROJECTION	0.001"	$50K+ PC/AT + POSITIONING
LASER DESIGN	3-D LASER DIGITIZER	LASER TRIANGULATION	0.002"	$75K - 100K
CHESAPEAKE LASER SYSTEMS	TDP 1000	LASER TRIANGULATION	1/1000 OF MAX HEIGHT	N/A
LOCKHEED	CUSTOM	LASER CONTOURING	N/A	N/A
WYKO	MAX	LASER CONTOURING	1/1000 OF MAX HEIGHT	N/A

Criteria for System Evaluation

- Positioning Method Selection
- Equipment Evaluation

Positioning Alternatives

* Attached Scanner System

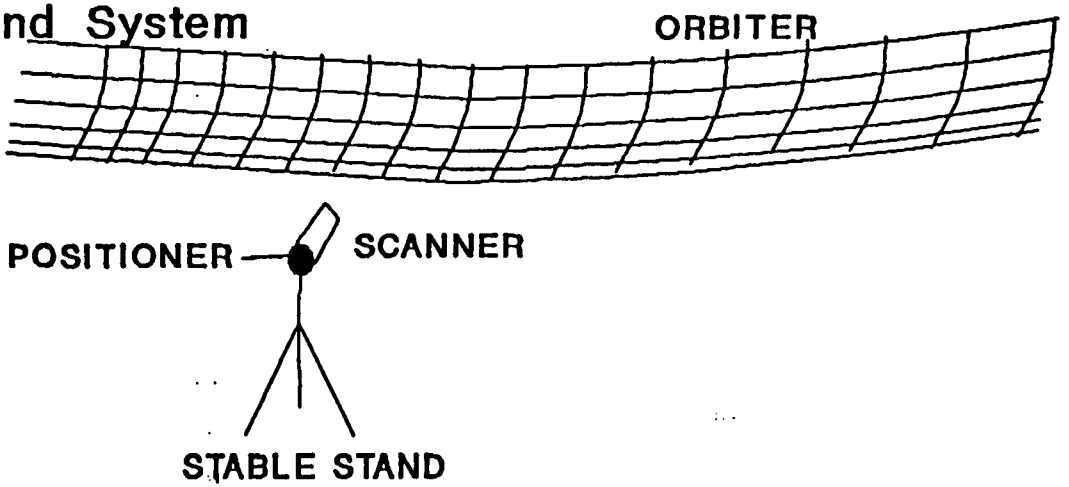


+ Compensates for shuttle motion (Dynamic Accuracy)
+ Eliminates need for splash
+ Compact, lightweight

- Contact to tile structure (Vacuum)

Positioning Alternatives
(cont.)

* Independent Stand System



+ Compact
+ True non-contact measurement

- Dynamic accuracy problem due to shuttle movement

Positioning Alternatives
(cont.)

- Multiple Light Source and Detector System

  + Faster cavity information capture
  + May reduce Dynamic Accuracy problem
  + Eliminates moving device on positioner

  - Increase in equipment cost
  - Bulky digitizer set-up

Criteria for Equipment Evaluation

- ACCURACY
  - X ACCURACY
  - Z ACCURACY
  - SAMPLING DENSITY
  - VIEW INTEGRATION ACCURACY
- PHYSICAL CONSIDERATIONS
  - DEPTH OF FIELD
  - FIELD OF VIEW
  - STANDOFF
  - SCANNER WEIGHT
  - SCANNER DIMENSIONS
- SPEED
  - SCANNING SPEED
  - DIGITIZING SPEED
- OUTPUT COMPATIBILITY (CAD)
- USER TRANSPARENCY
- EQUIPMENT COST
- PRODUCT SAFETY
- CUSTOMIZATION, ACCESORIES AVAILABILITY

Academic Research Outcome

- M.S. Research Report
  THREE DIMENSIONAL, NON-CONTACT SURFACE MAPPING SYSTEMS
- Submit technical paper to a conference

Further Studies

* Continuation of current efforts
* Follow up with promising vendors
* Experimentation at UCF with the technology as well as other applications
  (FHTIC proposal submitted and approved for $ 90 k+)

Current Effort

* Equipment Acquisition
* Design of Laboratory Experiment
* Cooperation with Subcontractors

VOICE DATA ENTRY

Project Objectives

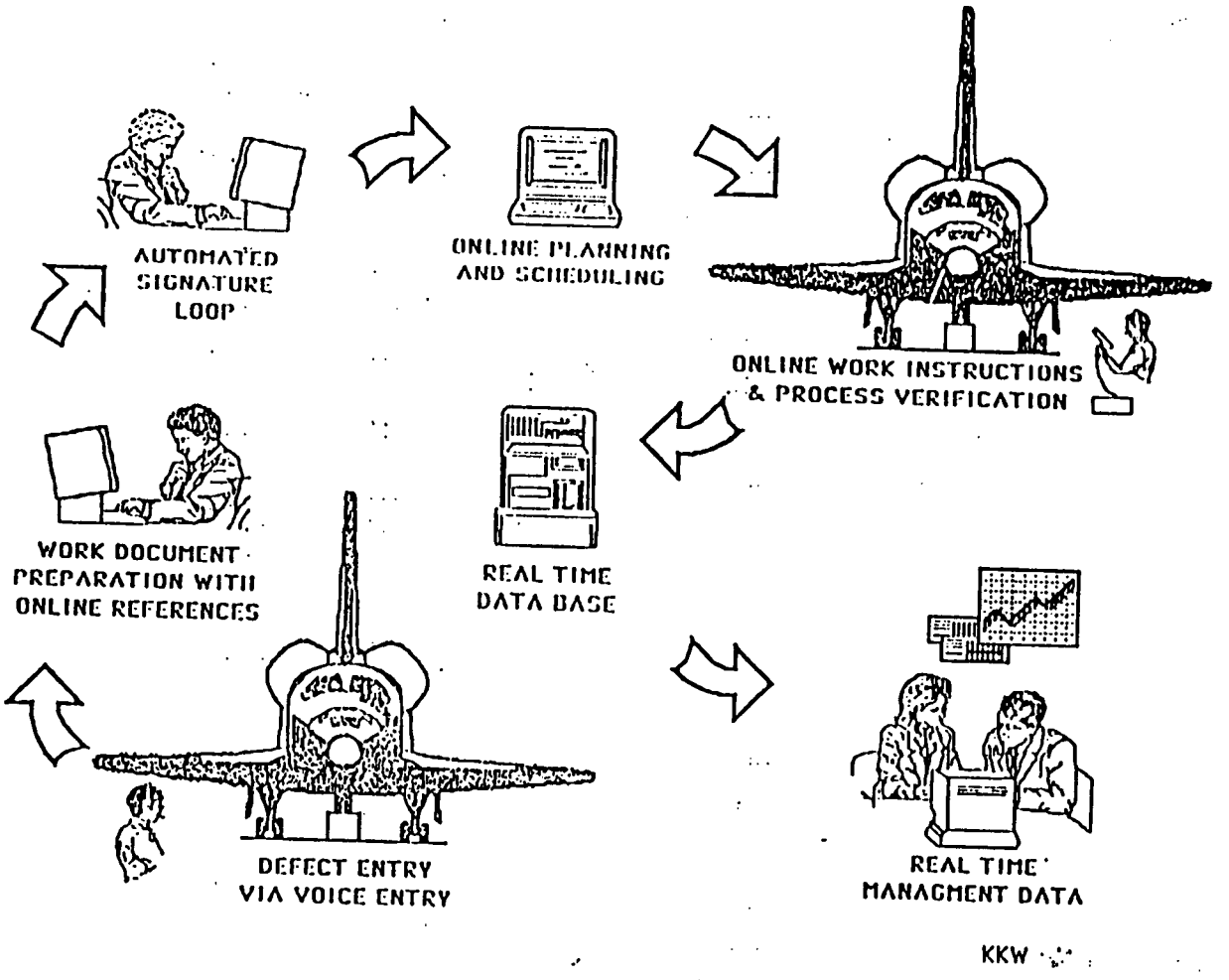
- Research voice technology applications.
- Develop a training strategy for VDES at KSC.
- Develop an implementation strategy for VDES at KSC.

Outline of Presentation

1. System Description
2. Training strategy
3. Implementation strategy
4. Recommendations
5. Outcome of Research

System Description

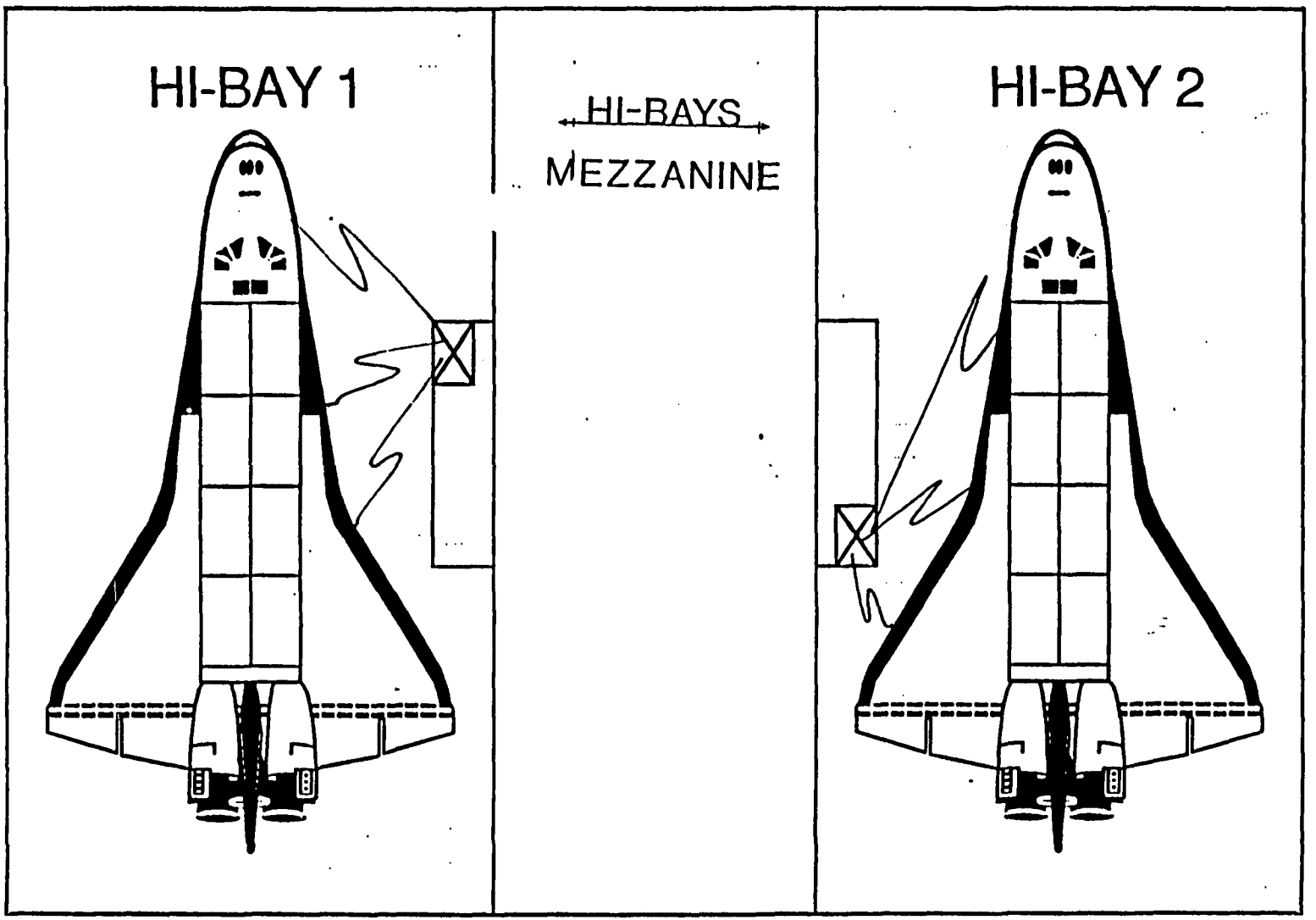
Automation Opportunities in TPS



UCF/ KSC Productivity Study, sl200-b

System Description

System Environment



ORBITER PROCESSING FACILITY (OPF)

System Description

Time Savings for VDES in P-310

	MANUAL	VDES
Log on	N/A	3
Cable prep	N/A	10
Tool & doc. prep	15	15
Tile measurement	3	3
Data entry & eval.	155	12
TOTAL	173 min.	43 min.

UCF/ KSC Productivity Study, sl700

Introduction of New Technology

- Training Strategy
- Implementation Strategy

Training Strategy
Identify Target Population

System Users:

- Tile Technicians
- QC Inspectors
- Management Supervisors
- Trainers

Training Strategy

For each user category:

- Identify Target Population
- Define Training Objectives
- Develop Training Aides and Identify Equipment
- Develop Methodology
- Develop Training Procedure
- Determine Measure of Effectiveness

TYPICAL STRATEGY

3.2.1 Strategy for TPS Technician and Quality Control (QC) Inspector

Target Population:

The target population for this training segment consists of TPS technicians with certifications 344 and 118, step and gap evaluation and step and gap measurement. The QC aspect of this training will be identical to the TPS technician training with the exception of the actual certification number. For maximum benefit, the trainee should also be certified for laser tool step and gap measurement.

Objectives:

The objectives of this training are:

1. Introduce the technician to the VDES and its benefits.
2. Train the technician to set up and take down equipment.
3. Train the system to recognize the trainee voice.
4. To use the VDES to produce a computer generated P-310 report with no error under normal hi-bay conditions.

Equipment:

1. VDES equipment (hardware and software) to be used on the job.
2. P-310 software.
3. Technician training manual. (Appendix II)
4. Step and gap case studies. (Appendix III)

Methodology:

The training consists of five approximately two-hour segments to be given on different days over the span of two weeks. The first segment starts with an overall description of the system to introduce the technicians to the VDES and its benefits. The video tape for VDES developed by Lockheed International may be used as an introduction to the system. At the beginning of this session the trainee will be provided with a document containing system description, the benefits associated with using the system, the user vocabulary and the software. Except for the short introductory segment, the first three sessions will be used mainly to provide the system with voice patterns for the technician. These sessions will require a one-to-one technician to trainer ratio with the current voice recognition training software provided by IVP. The fourth and fifth sessions will be used to train the technician on the use

of the P-310 software and to fill out a P-310 report under normal working conditions. During these sessions the technician will be given a copy of the P-310 report to make notes as needed on several case studies. The case studies provide the same information that would be available to the technician using the usual in the work environment such as step and gap measurements, tile numbers and spatial relations. One such method of providing this information would be to provide the technician with step and gap data maps for each case. The technician will then proceed to use the VDES in the hi-bay to generate P-310 reports for the case studies until they have completed three reports with no error.

Procedure:

Session One

1. Distribute the training manual and an introduction to the VDES and its benefits (verbal and or video introduction by trainer.)
2. Demonstrate the set up of the VDE equipment such as the headsets, and log on.
3. Take the first pass for the voice patterns in a quiet area.
4. Demonstrate the take down procedures for the VDE equipment such as return of headsets and log off.

Session Two

1. Have the technician set up equipment such as arranging the headset and logging on.
2. Demonstrate cable placement and hook up in the hi-bay.
3. Take the second pass for the voice patterns in the hi-bay.
4. Demonstrate cable unhooking procedures.
5. Have the technician log off and put up headphones.

Session Three

1. Have the technician set up the VDE equipment for use in the hi-bay.
2. Take the third pass for the voice patterns in the hi-bay.
3. Have the technician remove equipment from the hi-bay and log off.

Sessions Four and Five:

1. Provide the technician with a copy of the P-310 report and case studies. Appendix III contains case study scenarios. Explain that the case studies are to be used as if they were actual information

to be entered on the job and that completing three with no errors will conclude the training.

2. Have the technician set up the VDE equipment for use in the hi-bay.
3. Have the technician practice entering the case study information until three case studies have been entered correctly.
4. One such case study may involve entering data while performing the measurement (Manually or using the laser tool.)
5. Have the technician remove equipment from the hi-bay and log off.

This training scenarios should provide the TPS and QC technicians with a sufficient understanding of the VDES and P-310 software to incorporate these items into their work. The TPS tech should be able to be proficient in using the VDES for step and gap data entry. The QC inspector should be able to assure the integrity of the step and gap data with the understanding of the system.

Measure of proficiency:

- Successful set up of the system without trainer interference
- Completeness of three P-310 reports with no errors.

3.2.2. Strategy for VDES Trainer

Target Population:

The target population consists of the trainers and training specialists for the TPS who are involved in the VDES training. It is recommended that the trainer has an engineering background and familiarity with TPS and its operations.

Objectives:

1. Prepare the trainers to run the segments of the VDES system required for the training sessions fpr varopis target populations.
2. Familiarize and train the trainers on the use of training aids associated with various strategies.
3. Prepare the trainers to get feedback on current training techniques, system implementation and other areas where there may be the possibility of improvements.

Training Strategy
Technician Training Procedures

- Introduce VDES
- Train system
- Train for software
- Train Set-up
- Get feedback for possible improvements

Training Strategy
QC Training Procedures

- Introduce VDES
- Train to recognize proper set-up
- Train to recognize proper system use
- Get feedback on possible improvements

Training Strategy
Management Introduction Procedures

- Introduce VDES
- Give an appreciation of system benefits
- Get feedback on possible improvements and additional KSC implementation possibilities

Training Strategy
Trainer Training Procedures

- Introduce VDES
- Give an appreciation of system benefits
- Train system set-up and use
- Train training software use
- Train Technician, QC and Managerial Sessions
- Get feedback on possible improvements

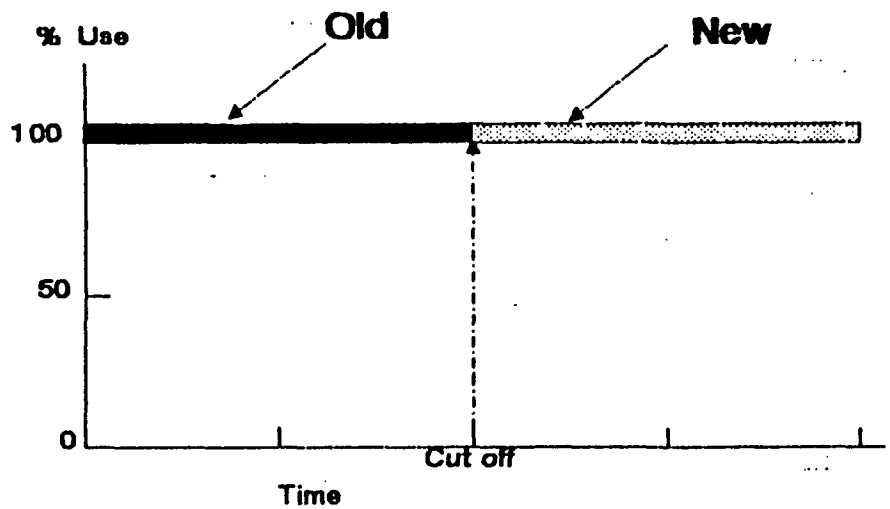
Implementation Strategy

Typical strategies for new system implementation:

- Cut off
- Gradual
- Parallel
- Combination

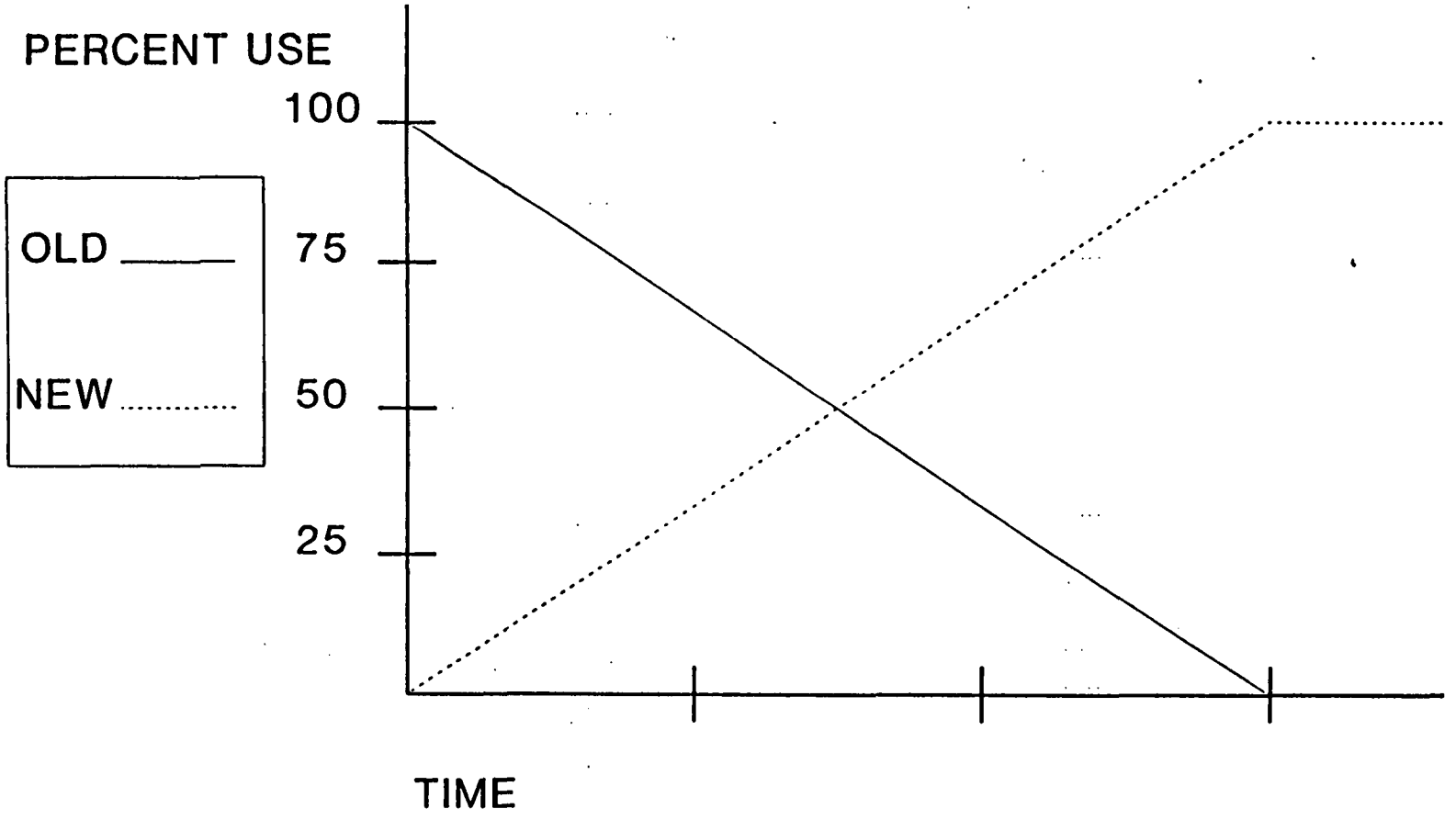
Implemetation Strategy

Cut Off Method



Implementation Strategy

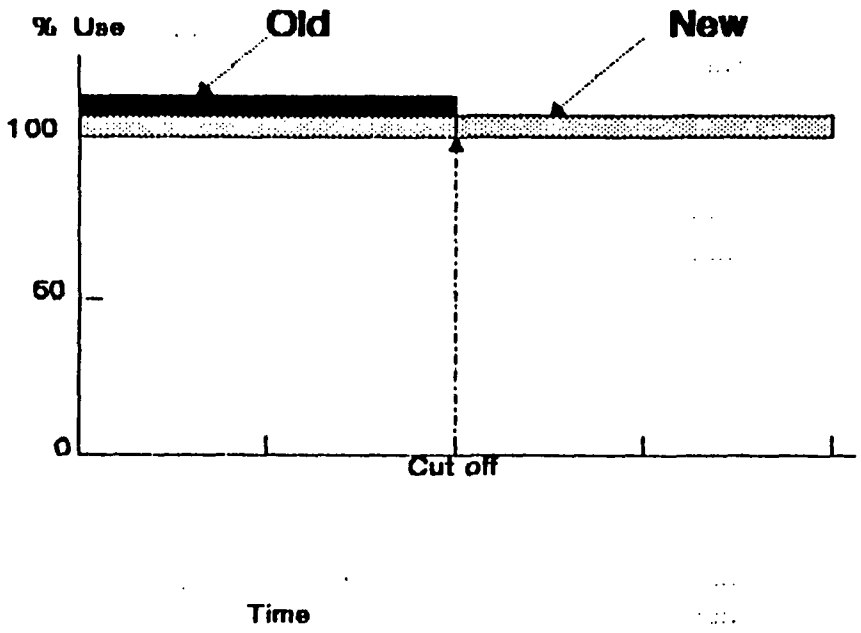
Gradual Method



UCF/ KSC Productivity Study, sl2900g

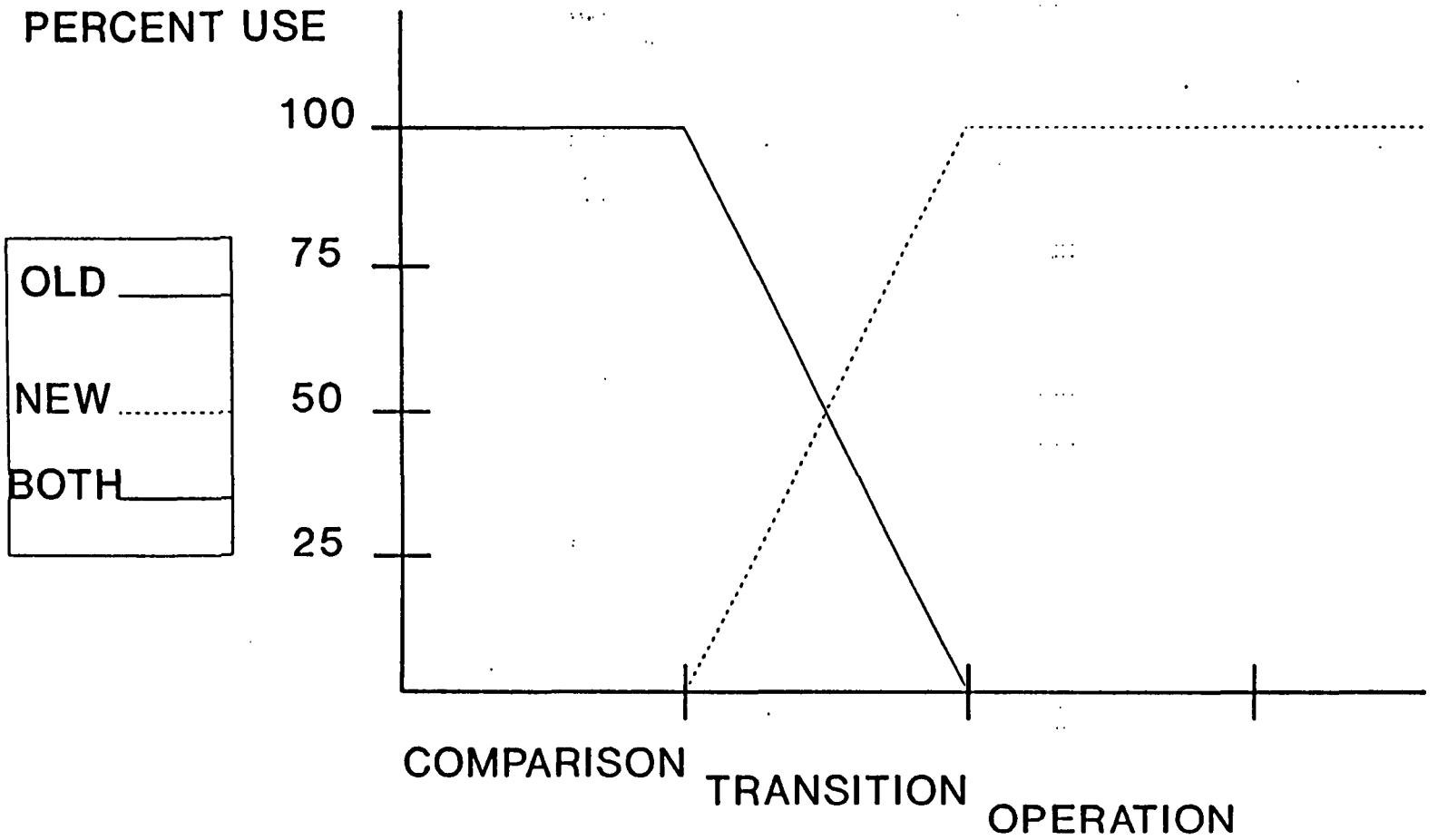
Implementation Strategy

Parallel Method



Implementation Strategy

Combination Method



UCF/ KSC Productivity Study, sl2800gr

Recommendations
Training

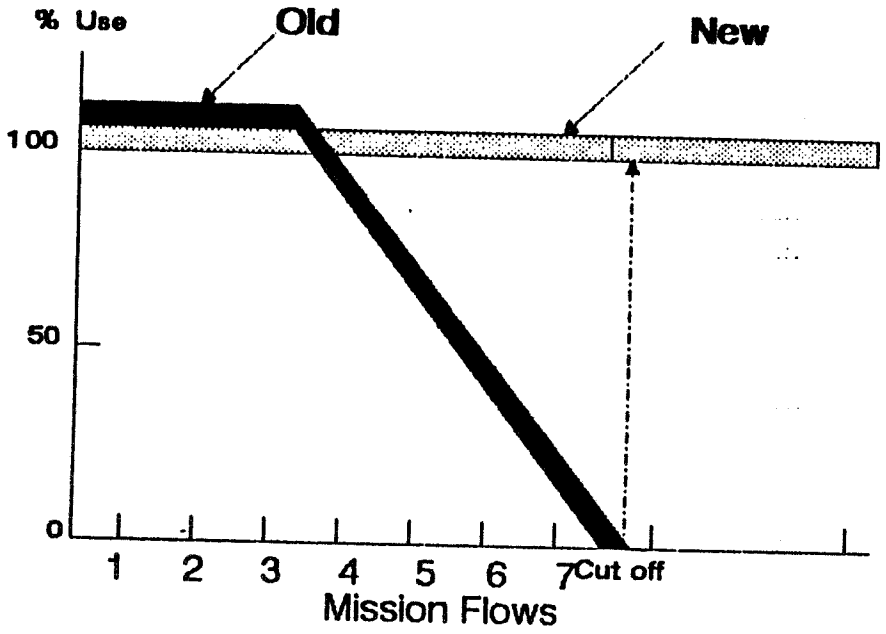
- Follow Training strategy presented
- Certify technicians for VDES at the end of successful training.
- Certify incoming technicians on VDES in lieu of manual operations

Recommendations
Implementation

- Parallel implementation for 4 flows to compare data entry methods
- Gradual implementation for 3 to 4 flows before cut off to allow complete training
- Increase the number of headphones and continue adaptation of hi bays for VDES

Recommended Implementation

Combination



Recommendations
General

- Add VDES to existing procedures to insure use.
- Eliminate recording of any unneeded data.
- Move to microcomputer based systems.
- Continue implementation of VDES for other OPF and KSC systems.
- Continue follow up study to determine training effectiveness and document findings in a technical paper.

Outcomes of Research
Technical Report

- Training manuals for training VDES in P-310
- Implementation strategy
- Training aids

Outcome of Research

By-products

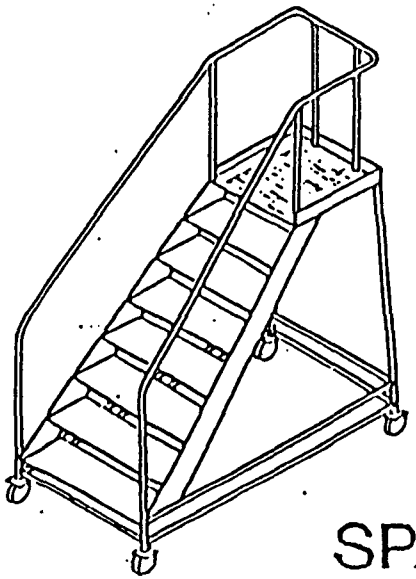
* Literature survey of voice systems
* Vendor survey
* Technical papers
* Equipment Acquisition

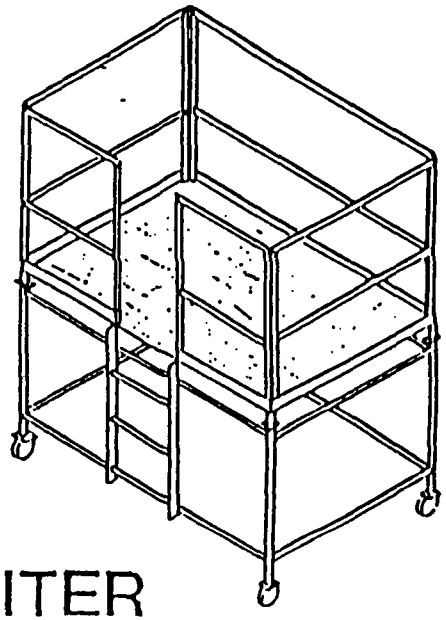
Current Effort

* Studying Microcomputer Based VDES
* Experimenting with RF Signal
* Feasibility with New Application
* Feasibility with Interfacing with KSC Mainframe

UNIVERSITY OF CENTRAL FLORIDA
INDUSTRIAL ENGINEERING PROJECT

WORKSTAND DESIGN COMPONENT





SPACE SHUTTLE ORBITER
THERMAL PROTECTION SYSTEM
PROCESSING

Justification for Workstand Study

- Need for improvement in TPS processing
- Engineering Challenge
- Little data exists for work performed in these positions
- Application to aerospace and other industries

Objectives

- Overall: Develop ergonomically improved workstand design
- Specific: Generate set of workstand specs
  Evaluate current stand design
  Create design alternatives
  Evaluate new designs
- Generation of technical paper and data in unresearched area

Procedure Followed

- Literature and Vendor Search
- Task Observation, Review of Processes
- Interviews - Technicians, supervisors, Shop Aids, engineering staff
- Evaluation of current stands
- Conceptual designs
- Evaluation of new designs

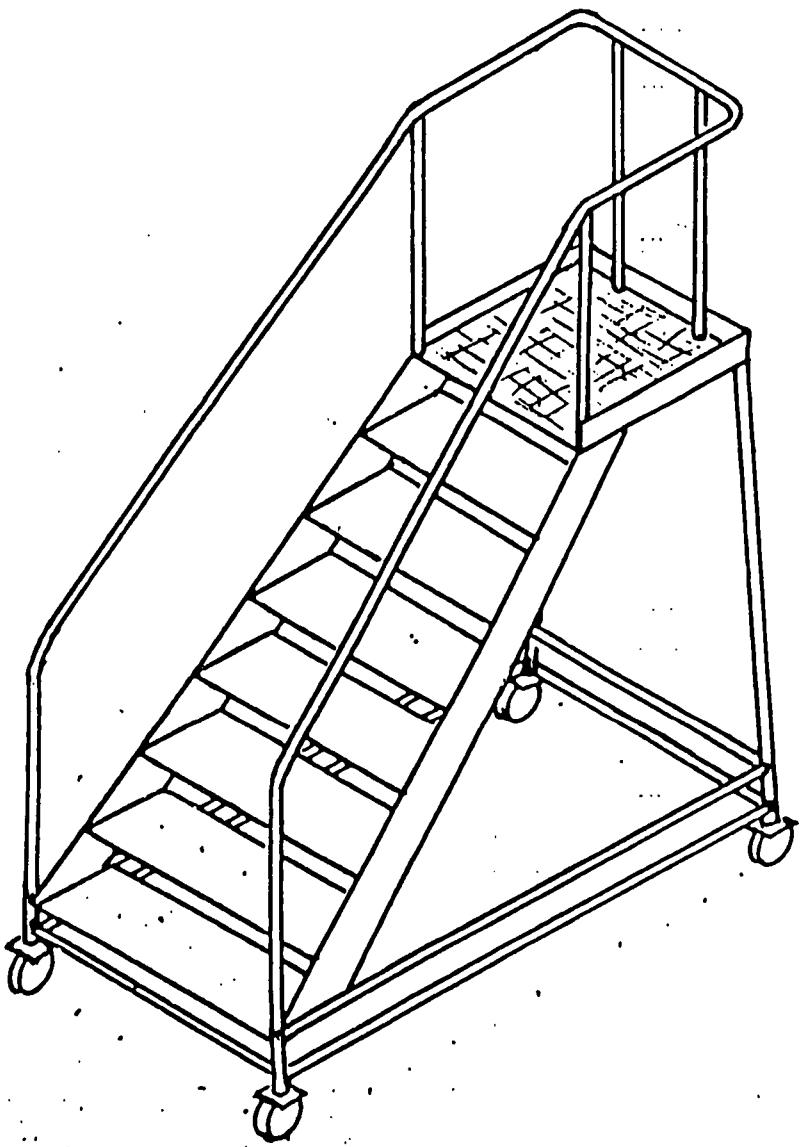
General Requirements

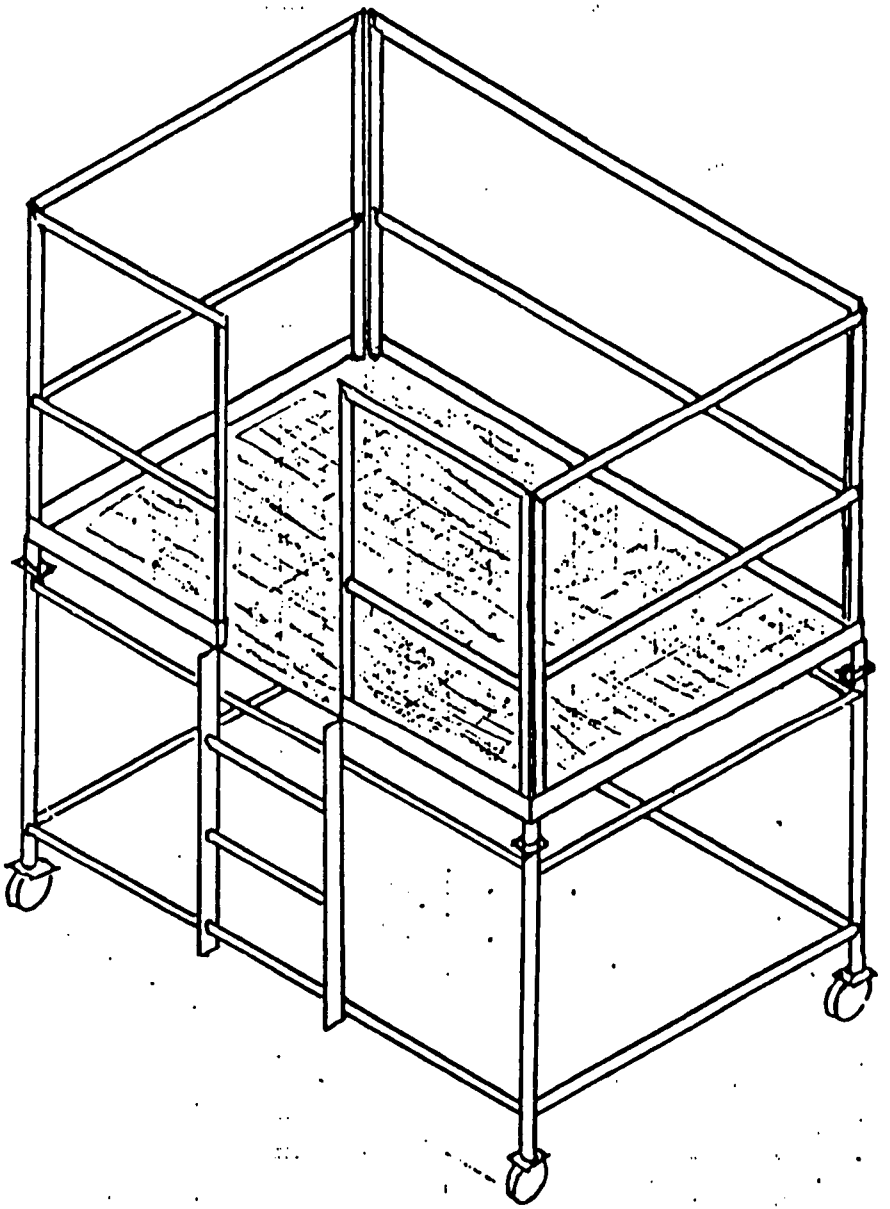
- Safe access to lower orbiter surfaces in range of 8 to 12 feet above OPF floor
- Ease of height adjustment and stand movement - safety and task performance
- Rigidity and stablity for precise work
- Easy ingress to and egress from work position
- Ergonomic considerations for unusual postures, equipment and paperwork access and storage

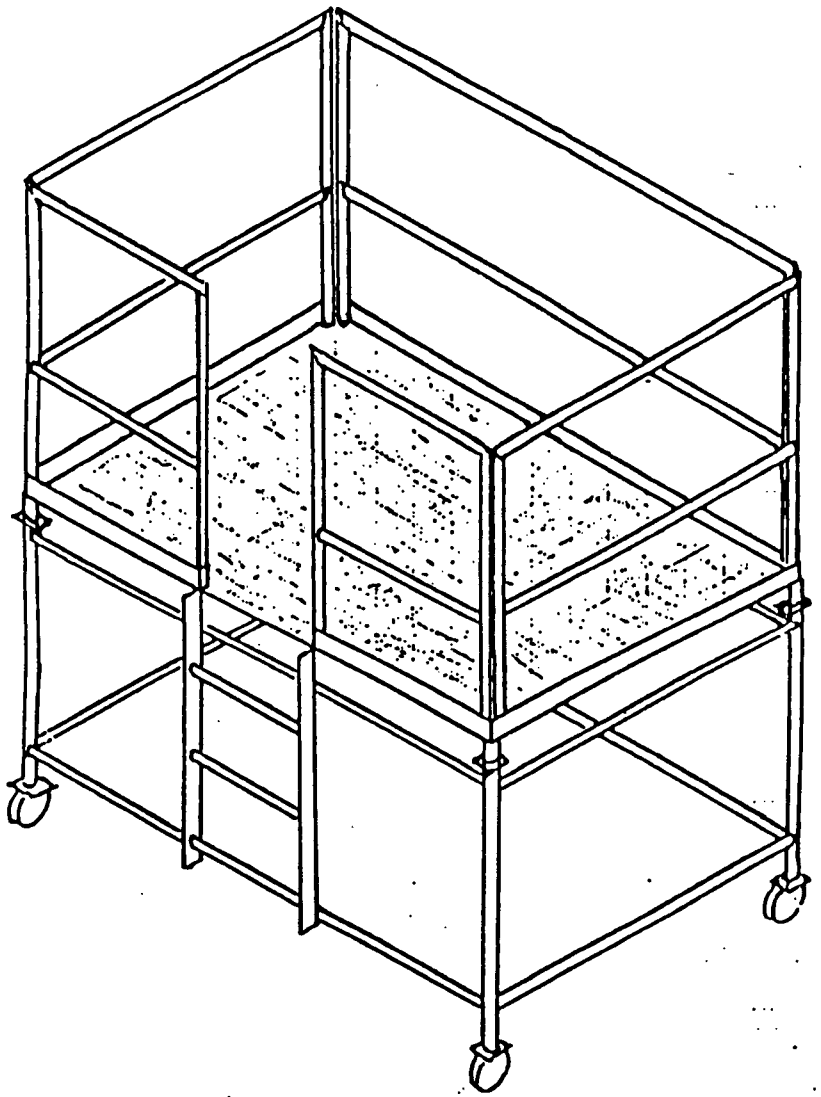
Specific Requirements

- Continous height adjustment accomplished from working position, preferably powered
- Postural support for tasks performed
- Wheel size
- Proof testing
- Compliance with NASA SW-E-0002, NSTS 08242, and MIL-STD-1427C

Current Stand Designs





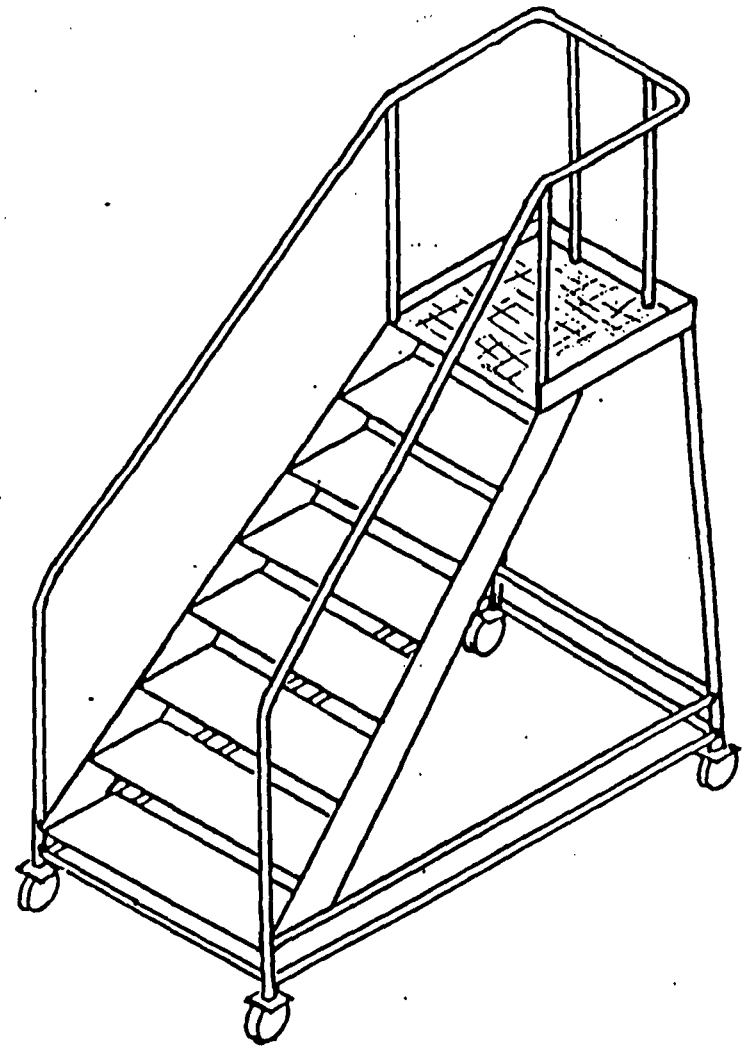


Current Stand Designs

- LARGE STANDS
  dimensions
  adjustment difficulties
  wheel size
  stability/rigidity
  equipment/paperwork access

Current Stand Designs

- SMALL STANDS
  dimensions
  non-adjustable height
  wheel size and number
  stability/rigidity
  equipment/paperwork access



Ergonomic Evaluation
Current Stands

- Work positions assumed
- Safety - slips or falls
  back/other injuries
    height adjustability
    mobility
- Human factors
    vision/visual acuity
    muscle fatigue/tremor
- Access to equipment and paperwork

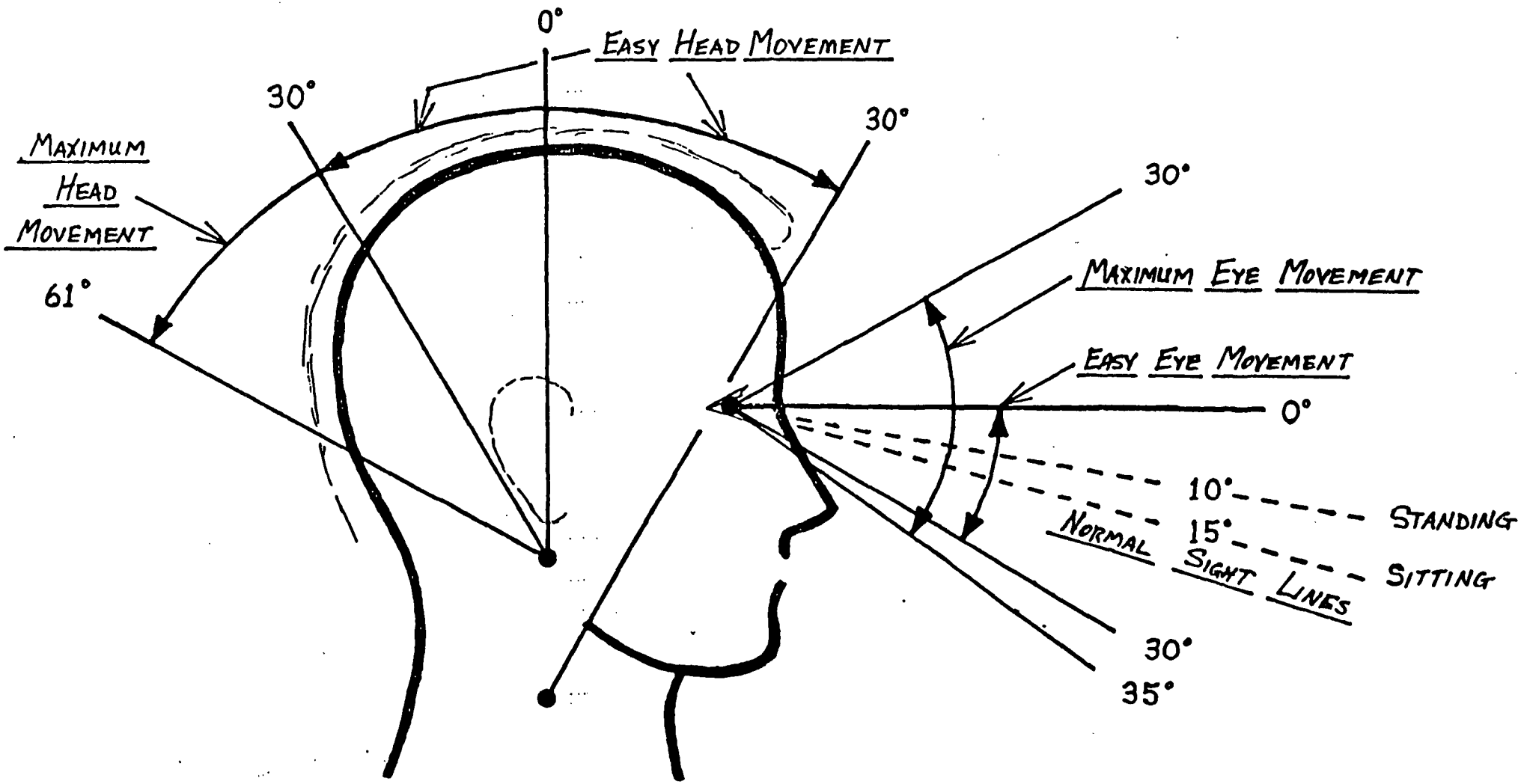
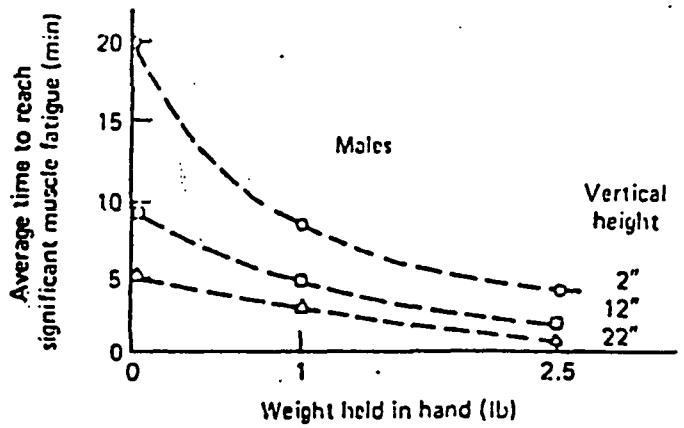
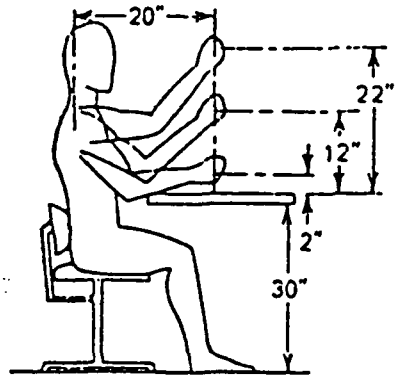
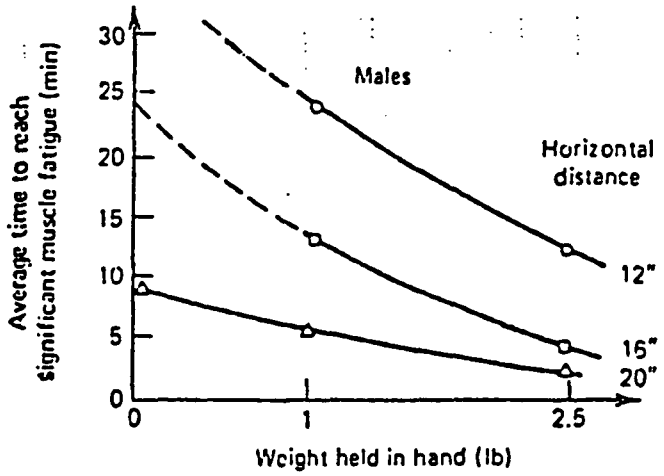


DIAGRAM 1

Head and Eye Movement







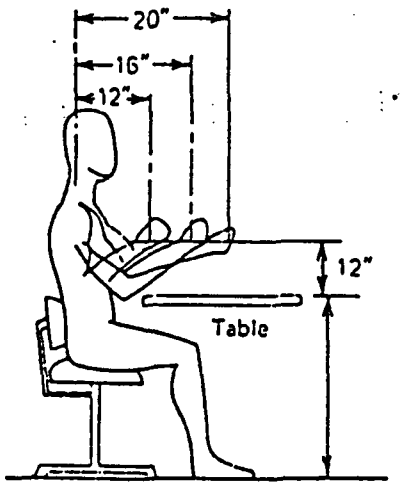


DIAGRAM 2

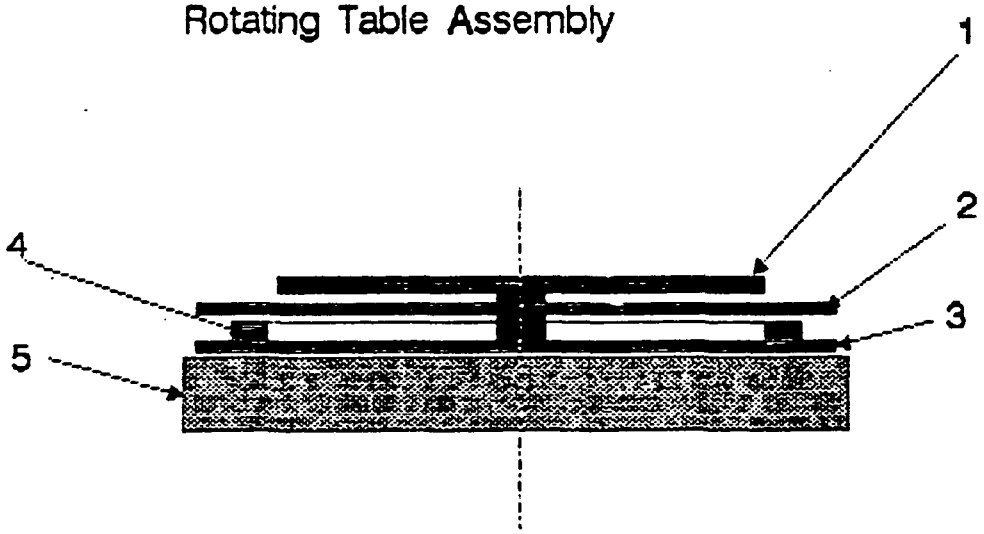
Time to Reach Muscle Fatigue

(Note: Data are for men. No more than two-thirds of the value shown should be used for women.)

New Workstand Designs

- Larger wheels
- Improvement in range/ease of adjustment
- Improved access to equipment/paperwork
- Features for body support of technicians while performing overhead work

Rotating Table Assembly



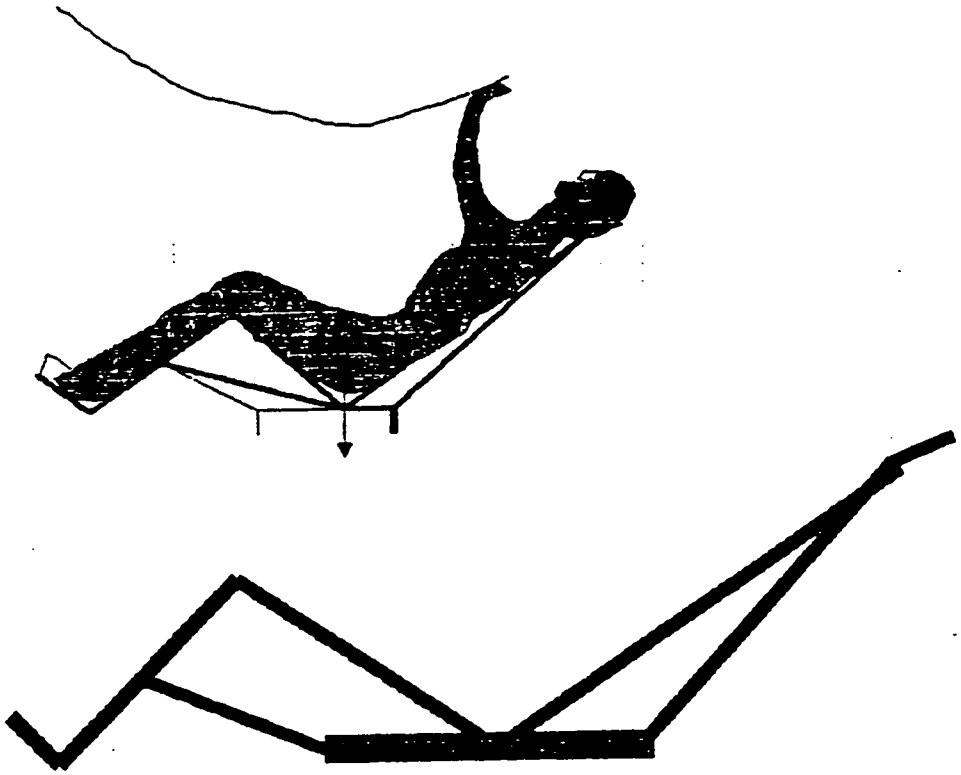
1. Fixed Upper Flange
2. Rotating Disc
3. Fixed Lower Flange
4. Copper Ring
5. Workstand (top)

Evaluation of New Designs
Further Study

- Refinement of Seat Design
  Experimentation with prototype:
  1. Optimization of critical dimensions
  2. Levels of performance degradation
  3. Comparison to current work postures

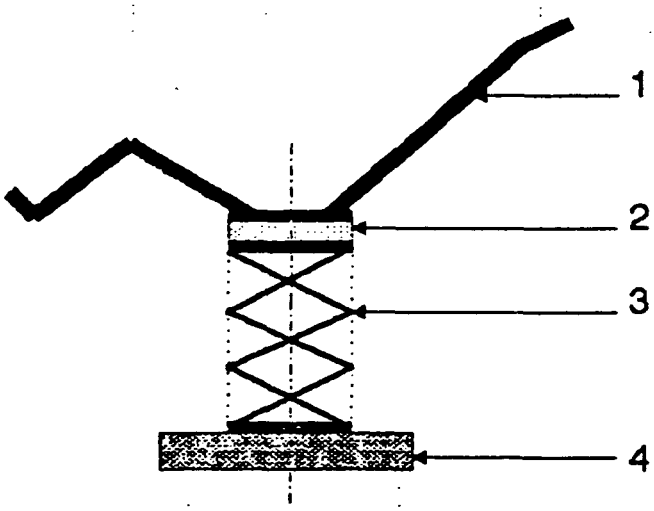
- Determination of "most suited" tasks
  1. Area of coverage performing task
  2. Overhead work exposure duration

- Final design and performance testing



Overhead Operations

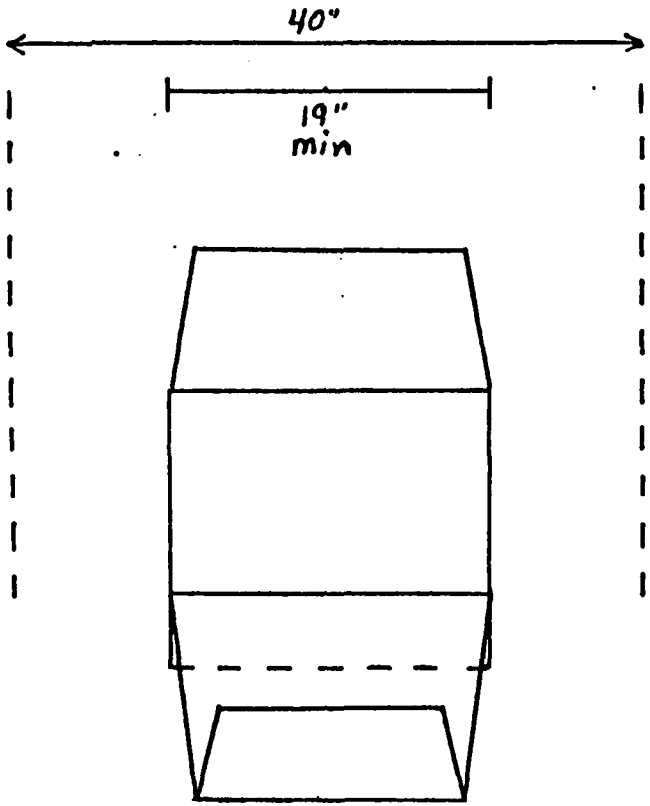
Workstand Assembly Components



1. Seat Frame
2. Rotating Table
3. Height Adjustable Mechanism
4. Workstand

PADDING DENSITY

Leg Support	None	-
Footrest	(None - non-skid surface)	
Seat Bottom	1"	Medium
Seat Back	1"	Soft
Headrest	1"	Soft
Lumbar Region	2"	Medium
Armrests (if used)	1"	Firm



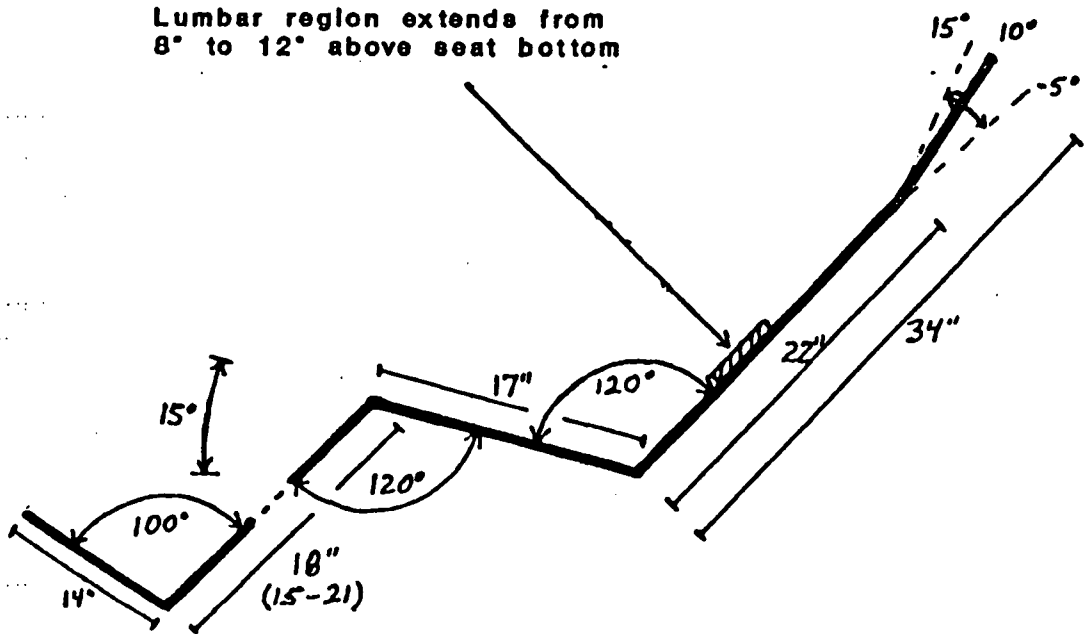
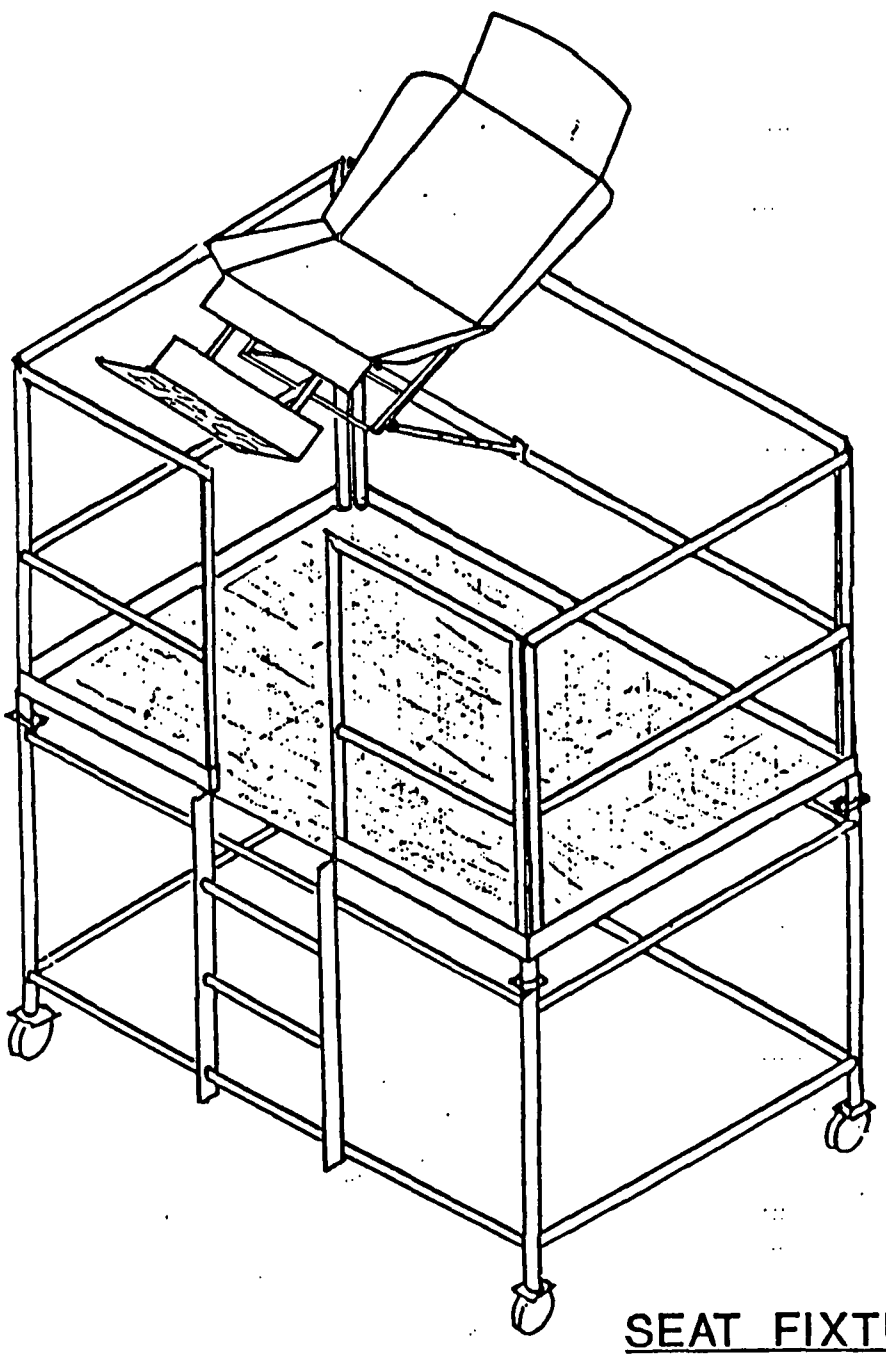


DIAGRAM 3

Semi-Reclined Seating Parameters



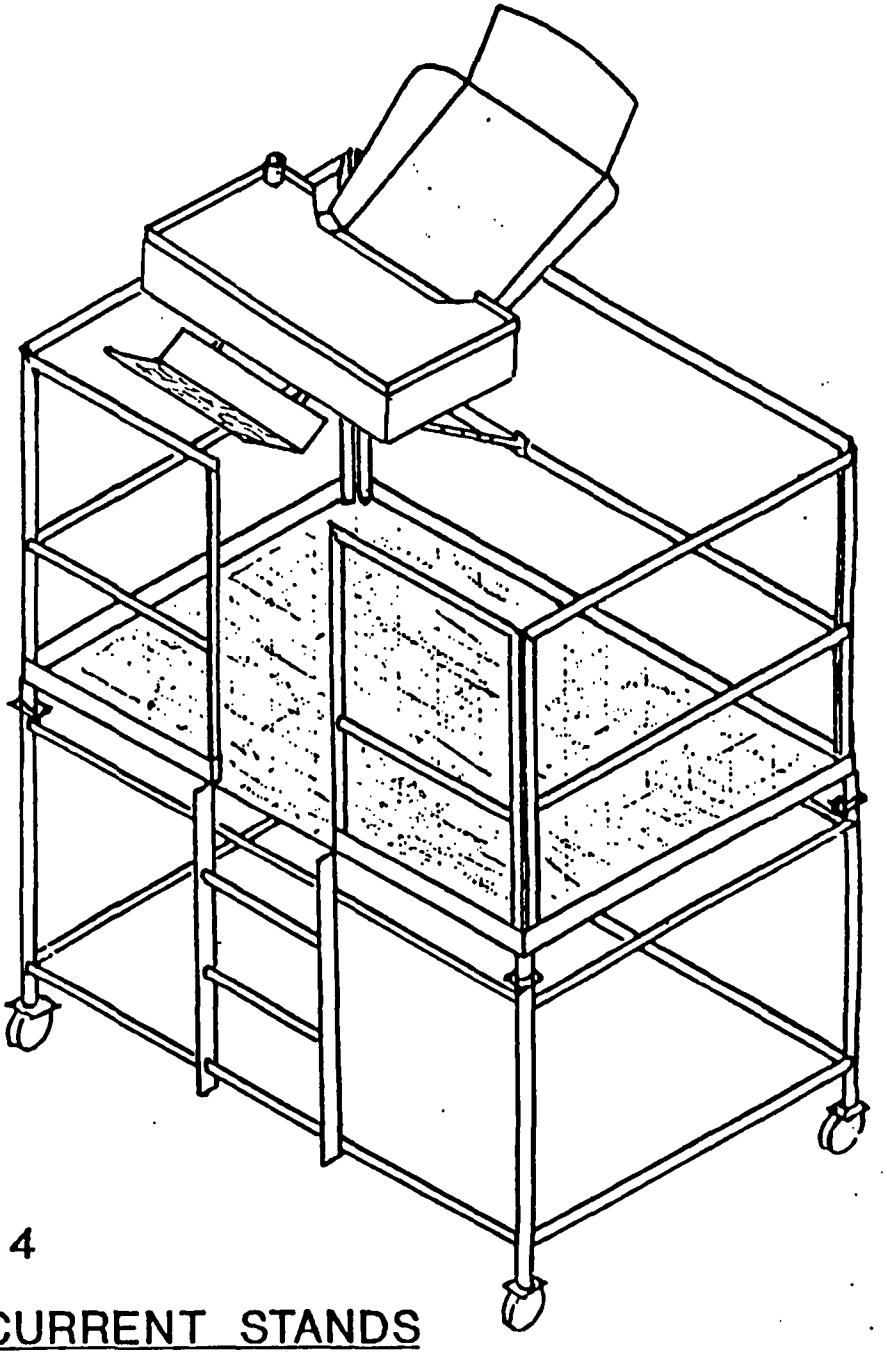


DIAGRAM 4

SEAT FIXTURE FOR CURRENT STANDS

Research Outcomes

- Technical Paper
- Generation of new data applicable to aerospace and other industries

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UNIVERSITY OF CENTRAL FLORIDA

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Contract Number:	NAG10-0058
Principal Investigator:	Dr. S. L. Rice
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Date of Report:	90/10/05
Title of Report:	Final Technical (Performance) Review Knowledge Acquisition for Artificial Intelligence, Productivity, and Materials Analysis Techniques
Project:	7 - NASA - Project Management
Security Classification:	Unclassified
Name of Issuing Government Activity:	NASA

UNIVERSITY OF CENTRAL FLORIDA
College of Engineering
P.O. Box 25000
Orlando, Florida 32816

FINAL TECHNICAL REPORT

TO

NASA/ Kennedy Space Center

FOR

RESEARCH GRANT

entitled

"NASA - PROJECT MANAGEMENT"
Task Definition: Summer 1989

NAG10-0058

May 11, 1990

Dr. Stephen L. Rice
Associate Dean & Professor
Principal Investigator
(407) 275-2156

Background

In the fall, 1988, exploratory meetings were held to determine ways in which the College of Engineering (COE) of the University of Central Florida (UCF) could assist Kennedy Space Center (KSC) in its mission oriented activities. In these meetings, NASA personnel briefed COE faculty of current projects and programmatic interests, and COE faculty presented their research interests, laboratory capabilities, and so forth. Based upon these exchanges it was evident that a number of projects could be conducted by UCF/COE faculty in support of KSC needs and mission objectives.

In March, 1989, UCF/COE submitted a proposal to KSC entitled "Cooperative Agreement for Technology Development -- Task Definition, Summer, 1989". The purpose of this proposal was "to enable improved problem definition and to initiate working relationships between UCF and KSC personnel". Several specific work areas were identified, including Shuttle Close-Out Data Systems, Public Affairs Information Retrieval, Knowledge Acquisition from Natural Language Input, Non-Destructive Evaluation, Corrosion Protection, and Shuttle Tile Processing. A second proposal followed in June, 1989, to extend the process of defining specific tasks which would form the basis of a Cooperative Agreement covering several areas of technology. These proposals were funded under Grant Number NAG10-0058.

Work Effort

Project management activites included several elements. First among these was setting up procedures for communication between the various colleges and departments involved in the project from the UCF side. Traditionally, universities are highly compartmentalized, however, KSC's need was to have projects operating between and within UCF's Colleges of Engineering, Business, Arts and Science, and Education. Within these various colleges, each faculty Principal Investigator (PI) is assigned to a base work unit which is his/her academic department. Thus, communication channels were set up to involve all of the cognizant college deans, and through them, the respective department chairpersons. The needs of each project were then addressed, and involved the assignment of laboratory and office space, and the setting up of project accounts, the hiring of graduate and undergraduate students and support staff, and so on.

A second major activity involved the development of accounting procedures, databases, and user-friendly formats for presentation of the data per se. This work was accomplished by the COE staff accountant, who developed information which allowed for overall control of funding available to each project and PI. Weekly meetings were held to review accounts and to evaluate budgetary situations. Additional meetings were conducted with each Principal Investigator to determine technical progress, and Program Review meetings were coordinated/held with KSC.

Each subproject has been implemented successfully, and has been supportive of overall KSC mission oriented goals. This has led to the subsequent funding of follow on work under a Cooperative Agreement. The administrative features of the original grant are successfully being applied in this new project as well.